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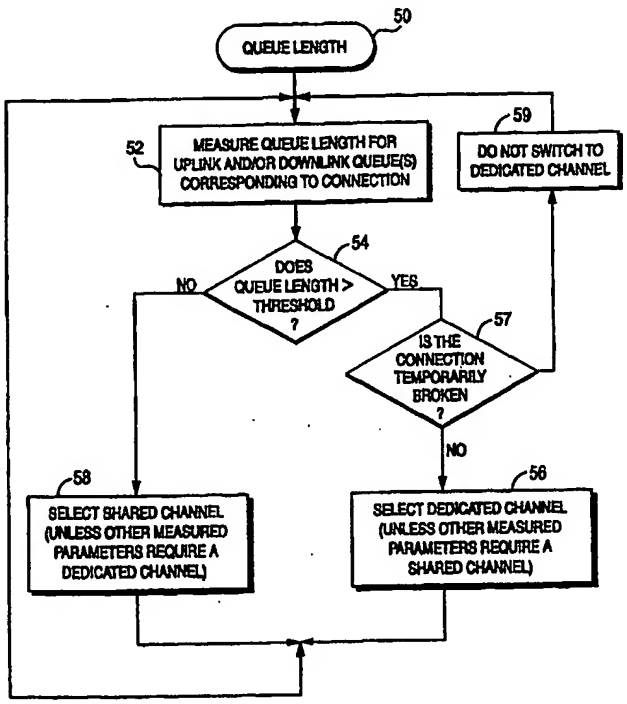
(54) Title: METHOD AND APPARATUS FOR DYNAMICALLY ADAPTING A CONNECTION STATE IN A MOBILE COMMUNICATIONS SYSTEM

(57) Abstract

In a mobile communications system that provides packet data services, a packet data connection is established between a mobile station and a radio access network. The state of the connection is used to specify one of plural different types of radio channels bearing the connection over the radio interface. The connection state preferably also may specify other parameters including, for example, one of plural different mobility management schemes tailored to the selected channel type or channel bit rate(s). The connection is dynamically adapted to an optimal state based on one or more conditions relating to the connection. For example, one or more traffic parameters are determined for the connection and may be used to predict a future value of that parameter. Based on the predicted parameter value or values, an optimal connection state is determined and implemented. If the predicted parameter value changes later in the connection, another connection state may be dynamically selected that is better suited in accordance with the newly predicted parameter value. One example embodiment is based on the amount of data in queue for a packet data connection. Comparison is made with one or more thresholds to decide which type of radio channel should bear the connection. Other factors, parameters, and conditions may be employed along with threshold comparisons to select the optimal radio channel type.



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METHOD AND APPARATUS FOR DYNAMICALLY ADAPTING A CONNECTION STATE IN A MOBILE COMMUNICATIONS SYSTEM

TECHNICAL FIELD OF THE INVENTION

The present invention relates to mobile communications, and in particular, to dynamically adapting a data communication connection to an optimal state.

BACKGROUND AND SUMMARY OF THE INVENTION

In current and future mobile radio communication systems, a variety of different services either are or will be provided. While mobile telephone systems have traditionally provided voice services, packet data services are also becoming increasingly important. Example packet data services include e-mail, file transfers, and information retrieval using the Internet. Because packet data services often utilize system resources in a manner that varies over the course of a packet data session, the flow of packets is often characterized as "bursty." Fig. 1 is a graph that illustrates packet bursts communicated over time and interspersed over periods where no packets are transmitted. In general, the "density" of packets is high for short time periods and often very low for long periods.

Mobile communication systems must be able to accommodate both circuit-switched services well suited for applications like voice as well as packet-switched services well suited for bursty data applications like e-mail, and at the same time, those services must efficiently use the limited radio bandwidth. In the context of these different types of services, mobile communication systems should provide different types of channels and different schemes for keeping track of the mobile location hereafter referred to as "mobility management."

The Global System for Mobile communications (GSM) offers two categories of services including circuit-switched services via a Mobile Switching Center (MSC) node and packet-switched services via a General Packet Radio Service (GPRS) node. For circuit-switched, guaranteed service, e.g., High Speed Circuit-Switched Data (HSCSD), statically-dedicated traffic channels are employed. For packet-based, best effort service, another set of packet data channels are allocated from a pool of resources on a per packet basis using a media access control protocol or scheduling policy. Mobile communication systems in North America based on IS-95 standard offer packet data services by supporting variable rate transmission on an established, dedicated channel.

There are significant drawbacks with these current approaches which statically map a connection-oriented or a connectionless-oriented service onto a specific channel type. Inevitably, such static mapping results in a non-optimal use of system resources. Packet-switched services, in particular, require variable bandwidths and delays. A high-bandwidth, short-delay packet service like packet-switched audio and video benefits from using a dedicated channel reserved during the connection. But other packet services like messaging and e-mail do not require high bandwidth or short delay. In fact, the bursty nature of e-mail and messaging services underutilize a continuously reserved channel. The present invention overcomes these drawbacks and achieves optimal use of system resources by dynamically determining and allocating a best connection state depending on the packet data to be currently transmitted. In one embodiment, the connection state may specify the type of radio channel. In other embodiments, the connection state may specify additional characteristics. For example, an optimal channel type and a mobility management scheme best suited for that particular channel type may be dynamically allocated.

In a mobile communications system, a connection is established between a mobile station and a radio access network. A "connection" refers to a service

provided by the radio access network to permit communication of information over a radio interface between the mobile station and the radio access network in both uplink (from the mobile) and downlink (to the mobile) directions. Such a connection may be established in response to the mobile station or by a core network connected to the radio access network. A connection may remain established even though the mobile station changes geographic cells/areas, i.e., a handover. The state of the connection specifies one of plural different types of radio channels to carry or bear the connection over the radio interface. The connection state preferably may also specify other characteristics such as one of plural, different mobility management schemes tailored to the selected channel type, channel bit rate(s), etc.

The connection is dynamically adapted to an optimal state based on one or more conditions relating to the connection. For example, one or more traffic parameters are determined for the connection and used to predict a future parameter value. Based on a predicted parameter value, an optimal connection state is determined and implemented. If the traffic parameter value changes later in the connection, another channel type may be dynamically selected that is better suited for the newly predicted parameter. Example traffic parameters are the amount of data to be sent in the future over the mobile data packet connection, packet arrival time, and packet density. A connection state may specify a radio channel type. Example channel types include a dedicated radio channel carrying data packets associated with only one mobile station and a shared radio channel carrying data packets associated with more than one mobile station. In addition, the shared radio channel type includes a temporary dedicated radio channel, a random access channel, and a paging channel. Taking the current amount of data in queue as an example traffic parameter, if the amount of data in the queue exceeds a threshold, it may be optimal to employ a dedicated channel to carry that high volume of data. Otherwise, it may be optimal to employ a shared channel.

In a preferred example embodiment based on the amount of data in queue for a packet data connection with a mobile station over a radio access network, if the determined amount of data in queue exceeds the threshold, it is also determined whether the packet data connection is temporarily disconnected or interrupted. If the packet data connection is temporarily disconnected or interrupted, no channel type decision or transfer is made. Otherwise, the packet data connection is established on or transferred to a dedicated radio channel. If the determined amount of packet data in queue is less than a threshold, a shared radio channel may be selected, or one or more other parameters may be considered in deciding what type of radio channel should bear the packet data connection. Preferably, such one or more other parameters relates to a flow of packets over the data packet connection. If the packet flow parameter exceeds a flow threshold, the packet data connection is allocated to a dedicated radio channel. If the packet flow parameter is less than or equal to a flow threshold, the packet data connection is allocated to a shared radio channel. An example flow parameter is the time interval between packets. When the determined time intervals between packets on the connection are similar, the packet data connection is assigned to a dedicated radio channel.

Such an example embodiment may be implemented in the downlink direction from the network to the mobile, although it may be used in the uplink direction as well. A network packet buffer is provided to store packets to be sent to the mobile station. A network packet router provides packets to the packet buffer. When the amount of packets currently stored in the packet buffer exceeds a predetermined percentage of the buffer size, the packet buffer generates a "back pressure" signal used to instruct the packet router to temporarily halt transmission of packets from the router to the packet buffer. The presence or absence of a back pressure signal may be employed in determining what type of radio channel should be allocated to bear the packet data connection.

In another example embodiment, the selected connection state may also specify one of plural mobility management (MM) schemes. In a first MM scheme, the mobile station's location is monitored on an individual cell basis. In a second MM scheme, the mobile station's location is monitored on a routing area basis, where a routing area includes plural cells. Still further, the connection state may specify the bit rate or bit rates. The bit rate may be fixed or, in the case of a variable rate channel, a maximum permitted rate or set of allowed bit rates. Of course, other and/or additional connection state parameters may also be employed.

In yet another example embodiment, an optimal connection state is dynamically selected for a packet data connection from a plurality of connection states based on a predicted traffic parameter, where each connection state specifies a particular radio channel type and a particular mobility management scheme. In this example, the traffic parameter may be packet arrival time, and a non-linear, neural network-based predictor may be used to predict a next data packet arrival time over the connection using data packet arrival times of most recent data packet arrival times. In addition to a single traffic parameter, e.g., next packet arrival time, a next connection state may also be based on other additional factors and considerations including, for example, a desired bearer service, a current connection state, a current radio interference level, and a current amount of data in a queue associated with the connection.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features, and advantages of the invention will be apparent from the following description of preferred example embodiments as illustrated in the accompanying drawings in which reference characters refer to the same parts throughout the various views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

Fig. 1 is a packet density diagram illustrating the bursty nature of packet data communication;

Fig. 2 is a function block diagram of a universal mobile telephone system in which the present invention may be advantageously employed in accordance with a preferred example embodiment;

Fig. 3 is a diagram illustrating example base station cells and routing areas;

Fig. 4 is a flowchart diagram illustrating example procedures in accordance with a Channel Select routine in accordance with an example embodiment of the present invention;

Fig. 5 is a flowchart diagram illustrating example procedures for dynamic channel type selection based on a current amount of data in a connection queue in accordance with an example embodiment of the present invention;

Fig. 6 is a diagram showing various buffers that may be employed in a UMTS network;

Fig. 7 is a flowchart diagram illustrating channel type selection procedures in accordance with an example embodiment of the present invention;

Fig. 8 is a flowchart diagram illustrating example procedures for implementing a Connection State Adaptation routine in accordance with an example embodiment of the present invention;

Fig. 9 is a connection state diagram in accordance with an example embodiment of the invention;

Fig. 10 is a function block diagram illustrating an example implementation of the present invention in the context of the mobile communications system shown in Fig. 2;

Fig. 11 is timing diagram illustrating data packet arrival times;

Fig. 12 is flowchart diagram illustrating example procedures in accordance with a Packet Arrival Time Predication routine in accordance with a preferred example embodiment of the present invention;

Fig. 13 is a diagram illustrating a connection state selector used to select a next connection state in accordance with a preferred example embodiment of the present invention; and

Fig. 14 is a diagram illustrating the non-linear predictor shown in Fig. 13.

DETAILED DESCRIPTION OF THE DRAWINGS

In the following description, for purposes of explanation and not limitation, specific details are set forth, such as particular embodiments, data flows, network elements, techniques, etc., in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details. For example, while the present invention is described in the context of a universal mobile telecommunications system that uses GSM/UMTS terminology, those skilled in the art will appreciate that the present invention can be implemented in any mobile communications system. In addition, while much of the description focuses on radio channels, those skilled in the art will recognize that the present invention may be applied to any packet data communications environment. In other instances, detailed descriptions of well-known methods, interfaces, devices, and signaling techniques are

omitted so as not to obscure the description of the present invention with unnecessary detail.

The present invention is described in the context of a universal mobile telecommunications system (UMTS) 10 shown in Fig. 2. A representative, circuit-switched, external core network, shown as a cloud 12 may be for example the Public Switched Telephone Network (PSTN) and/or the Integrated Services Digital Network (ISDN). A representative, packet-switched external core network shown as a cloud 14, may be for example the Internet. Both external core networks are connected to corresponding service nodes of the UMTS core network 16. The PSTN/ISDN circuit-switched network 12 is connected to a circuit-switched service node shown as a Mobile Switching Center (MSC) node 18 that provides circuit-switched services. In the existing GSM model, the MSC 18 is connected over an interface A to a Base Station Subsystem (BSS) 22 which in turn is connected to radio base station 23 over interface A_{bis}. The Internet packet-switched network 14 is connected to a General Packet Radio Service (GPRS) node 20 tailored to provide packet-switched type services. Each of the core network service nodes 18 and 20 connects to a UMTS Radio Access Network (URAN) 24 over a radio access network (RAN) interface. URAN 24 includes one or more radio network controllers 26. Each RNC 26 is connected to a plurality of base stations (BS) 28 and to any other RNC's in the URAN 24.

In the preferred embodiment, radio access is based upon wideband, Code Division Multiple Access (WCDMA) with individual radio channels allocated using WCDMA spreading codes. WCDMA provides wide bandwidth for multimedia services and other high rate demands as well as robust features like diversity handoff and RAKE receivers to ensure high quality.

The URAN 24 provides services between mobile stations 30 and UMTS core network service nodes 12 and 14 (and ultimately to external core network end users). With respect to example embodiments of the present invention described

hereafter, the term connection describes an information transfer service provided by the URAN 24. A connection permits transfer of user data information, e.g., packet data, in one or several information streams (bearers) as well as transfer of control signaling information between a mobile station 30 and the URAN 24 in both uplink and downlink directions. Such a connection is established upon request by the mobile station 30 or one of the UMTS core network service nodes 18, 20 and is maintained even as the mobile station moves. In accordance with the invention, the type of packet data service or the connection state may be selected and dynamically changed or adapted to optimize use of radio communication resources.

One type of packet data service is a dedicated service where a dedicated radio channel is continuously reserved between the mobile station and the URAN and is not shared with other mobile stations. Another type of packet data service is a shared service where more than one connection uses the same radio channel, i.e., plural mobile stations share the single channel. In addition to managing different types of radio channels, the mobility of a mobile station is preferably (though not necessarily) managed differently in the present invention depending upon the type of service selected for the connection. Other parameters, such as the connection's bit rate(s), may be specified by the connection service.

Fig. 3 is a diagram showing a plurality of adjacent cells, each cell having a corresponding base station. For the dedicated service, when a dedicated radio channel is allocated to a single mobile station, a handover procedure is preferably employed to maintain the connection by transferring it from one base station to another as the mobile moves between cells. Soft and softer handover procedures may preferably be employed in a CDMA system.

For a shared radio service, it may be more efficient to manage mobility from a signaling point of view. A shared radio channel associated with a shared radio service will typically be selected for low traffic and/or where a packet transfer delay is

acceptable. In these situations, a mobility management scheme based upon mobile station registration is preferred. When the mobile station enters a new cell, it sends a registration message to the associated network. However, in periods of low traffic from that mobile station, it is unnecessary for the mobile station to register in every cell. In fact, cell update messages may produce as much traffic or even more traffic than substantive user data traffic. For that situation, a next level of registration based on routing areas is desirable. Fig. 3 shows two routing areas: one encompassing four adjacent cells and a second encompassing two adjacent cells. If a mobile station changes routing areas, it sends a routing area registration message to the nearest base station. The network stores the routing area identification number where the mobile station last registered. When a data packet is to be sent to that mobile station, the network sends a page to the mobile station, and the mobile station sends a page response to identify the cell where packets should be sent.

With respect to one example embodiment of the invention that focuses just on channel type, Fig. 4 illustrates in flowchart format a Channel Select routine (block 40). Accordingly, the "connection state" in this example is characterized by channel type. However, the connection state may specify a different characteristic or more than one characteristic.

Assuming that a connection is already established between the mobile station and the URAN, a current value of one or more traffic parameters associated with that packet data connection is measured (block 42). It may be desirable to make separate measurements of the one or more parameters in both the uplink and the downlink directions because different channel types may be allocated to the uplink and the downlink and because the channel type and mobility management scheme depend on the traffic in both uplink and downlink directions. From the measured value(s) of the one or more connection parameters, the optimal type of channel is determined to carry future packet data to be sent over the packet data connection (block 44). Packet

data are then sent over the selected type of radio channel (block 46). A decision is made in block 48 whether one or more conditions have changed, and if so, the Channel Select routine repeats. As a result, the optimal type of channel for the current situation is dynamically determined and allocated so that system resources are efficiently employed.

An optimal channel type may be dynamically/adaptively determined and allocated based on a single, relatively simple parameter such as the amount of data currently stored in a connection queue, i.e., queue length, as described now in conjunction with the Queue Length routine (block 50) shown in Fig. 5. Queue length may be a good predictor of future data packet traffic intensity especially in the downlink direction to the mobile. This is useful because in some packet applications, the larger blocks of data are communicated in the downlink direction to the mobile. Of course, current queue lengths may be specified in an uplink and/or downlink queue(s) corresponding to the connection. Alternatively, a total payload parameter corresponding to the sum of the uplink and downlink queue length may also be employed.

A decision is made in block 54 whether the measured queue length exceeds a threshold. If it does, a decision may be made to select a dedicated type channel (block 56). Even though the large queue length indicates that a dedicated channel is appropriate, it may be desirable or necessary to consider other measured parameters which may dictate otherwise. For example, it may be that the connection has been temporarily broken or interrupted (block 57). If so, it is better not to switch channels (block 59) since the large queue is likely the result of the interrupted connection. If the queue length does not exceed the threshold, it may be more optimal to transport the smaller payload over a shared type channel (block 58). This decision may also be "overruled" if other parameters are taken into account which, on balance, indicate that a dedicated channel is either required or more optimal.

Another example channel type selection embodiment which takes into account queue length or the amount of data in a packet buffer is now described in conjunction with Figs. 6 and 7. Fig. 6 is a diagram of a generic UMTS core network node 16 that includes a packet router 100, a packet buffer 102, and a packet window buffer 104. The packet router 100 receives data packets from an external network to be transmitted to a particular mobile station over a packet data connection via the URAN 24. The packet router 100 includes a buffer for storing those data packets and for transferring them at a particular rate to the packet buffer 102 used to interface with the URAN 24. Packets from the packet buffer 102 are then delivered to the mobile station via the URAN 24 using an optimally selected radio channel.

When large amounts of data are provided from the packet router 100 to the packet buffer 102, the packet buffer 102 may not be of sufficient size to store all of the data. As a result, a "back pressure" mechanism is employed to manage packet flow and transfer. More specifically, a back pressure signal is transmitted from the packet buffer 102 back to the packet router 100 when the amount of data in the packet buffer 102 exceeds a particular percentage, e.g., eighty percent, of its maximum capacity. The back pressure signal is thereafter removed when the amount of data in the packet buffer 102 is less than a lower percentage, e.g., thirty percent, of its maximum capacity. The back pressure mechanism temporarily buffers in the packet router buffer 100 rather than in the packet buffer 102 because the packet router buffer 100 is considerably larger than the packet buffer 102. Also, it may be more optimal for higher layer protocols, e.g., TCP, to make decisions to discard packets on the IP-level when the packet router buffer 100 is full rather than when the packet buffer 102 is full.

A protocol sending window buffer 104 stores the packets transmitted from packet buffer 102 to the URAN 24 that have not yet been acknowledged by the URAN as accurately received. When a packet stored in the protocol sending window buffer 104 is acknowledged as accurately received, it is removed. If an accurate

acknowledgment is not received within an appropriate time for a transmitted packet, that packet is then retrieved from the packet window buffer and retransmit. In situations where the protocol sending window buffer 104 fills up to a certain level with outstanding packets not yet acknowledged, it can be reasonably inferred that there is a problem with the radio channel connection. For example, the radio could be behind a building, under a bridge, going through a tunnel, etc. or there may be excessive interference, such as in a crowded cell. Such circumstances are usually temporary. When the maximum number of outstanding acknowledgments is reached, the packet sending window is determined to be full. As will be described below, a "full window" may be taken into account in the channel type selection process.

Reference is now made to the Channel Type Selection routine (block 110) shown in flowchart form in Fig. 7. An amount of packet data currently stored in the packet buffer 102 is determined (block 112). A decision is made in block 114 whether the determined amount is less than X percent of the maximum packet buffer size. If so, another decision is made (block 118) whether a back pressure signal currently exists. If not, the relatively small amount of data in the packet buffer and the lack of back pressure suggest that it is desirable to select or transfer the packet data connection to a common or shared channel (block 122). As another alternative embodiment, a secondary channel type selection procedure may be performed at this point to determine the optimum channel type to carry the mobile connection rather than automatically selecting a common channel (block 122). The secondary channel type selection procedure may be based on current or predicted traffic intensity, packet arrival times, time between packets, and other parameters related to packet flow.

If the amount of data currently in the packet buffer 102 exceeds or is equal to X percent of the maximum buffer size, a decision is made (block 116) whether that amount is greater than or equal to Y percent of the maximum buffer size of the packet buffer 102, where Y is larger than X. The two threshold comparison process

adds hysteresis to prevent unnecessary or at least too frequent switching of channel type. Thus, if the amount does not exceed Y percent, a hysteresis type of decision is made in block 128. For example, a decision is made whether the buffer size decreased from being greater than Y to less than Y or whether the buffer size increased from being less than X. If the buffer size decreased from being greater than Y, a dedicated channel is selected (block 130). However, if the buffer size increased from being less than X, a common channel is selected (block 132). In an alternative embodiment, secondary channel type selection procedure such as that described for block 122 may be employed (block 132) rather than automatically always selecting a common channel. A secondary channel type selection procedure adds flexibility to the more rigid threshold comparisons in blocks 114 and 116.

On the other hand, if the amount of data currently in the packet buffer 102 exceeds Y percent of the maximum buffer size, a decision is made in block 120 whether data is currently flowing out of the packet buffer 102. This determination is made by the protocol sending window buffer 104 as described above with respect to Fig. 6. If a full window signal is generated by the protocol sending window buffer 104 indicating a broken or interrupted connection, a decision is made that data is not flowing out of the packet buffer 102, and the current channel type is maintained (block 126). That no data is flowing out from the buffer may be due to temporary hostile radio channel conditions, which are rather common in cellular systems. If data is flowing out of the packet buffer 102, (no full window signal), such a large amount of data currently in the packet buffer suggests that it would be better and/or more efficient to select or switch to a dedicated channel to carry the call connection (block 124). Similarly, if a back pressure signal is generated by the packet buffer 102 to the packet router 100 (block 118), the same decision is made in block 120 assuming data is flowing out of the packet buffer 102. The back pressure condition suggests that there is considerable data to be transmit and that it would be better and/or more efficient to switch to a dedicated channel to carry that data to the mobile (block 124). If the

protocol sending window buffer 104 generates a full window signal, the current channel type may be maintained (block 126) despite the back pressure condition.

With respect to the secondary channel type selection procedure referenced in blocks 122 and 128, packet arrival time may be a preferred criterion for delay sensitive applications like voice over IP which produce a long stream of regularly spaced (in time) small size packets. These packets may not aggregate to a large amount of data in the packet buffer 102 sufficient to warrant selection or switching to a dedicated channel. Nevertheless, low delay is important for voice over IP which typically requires a dedicated channel. Thus, the secondary channel type selection procedure may determine the amount of time between received packets of a connection and is fairly regular, and decide to select or switch to a dedicated channel. Hysteresis is also preferably employed in the secondary channel type selection procedure.

In another preferred example embodiment of the present invention, a packet arrival rate or a packet density for a particular data packet connection may be used to predict the future packet flow for a particular connection. That prediction may be used to determine the optimal type of channel and preferably also the type of mobility management scheme to use during a connection. Of course, other parameters, such as the connection's bit rate(s), the current number of idle devices like receivers in each base station, the current number of idle spreading codes, etc. may also be specified. For convenience and simplicity, "connection state" hereafter for this example embodiment refers to a radio channel type and/or a type of mobility management scheme. However, those skilled in the art will appreciate that other connection state parameters are encompassed by the present invention.

Depending on newly predicted packet flows, the selected channel type and/or mobility management scheme may be changed several times for the connection. An example of how the selected channel type may change between a dedicated and a shared type channel during a connection is now described. Two data amount thresholds

may be employed to introduce hysteresis into the channel type decision. Changing channel types requires a certain amount of signaling "overhead" (including delay and interference) for channel setup and take down. This overhead is sometimes more significant than the advantage to be gained by switching channel type. As mentioned earlier, hysteresis is beneficial because it restricts channel type changes to those that are worth the overhead associated with the change. More specifically, when the amount of data to be transmitted is large and exceeds a higher one of the two thresholds, the shared channel may be changed to a dedicated channel. If the amount of data is between the two thresholds, no change is made. If the amount of data to be transmitted is small and less than the lower one of the thresholds, a common or shared channel is selected.

In a preferred, example embodiment, the lower threshold is at or near zero so that an entire amount of data present/in queue is transmit over the dedicated channel before any channel type switch is made. It may also be desirable when the amount of data to be transmit is small, to determine an average intensity parameter or other parameter such as average packet arrival time. If that average traffic intensity or other parameter exceeds a parameter prescribed amount, then it may be preferable to maintain the existing dedicated channel.

Accordingly, once a dedicated channel is assigned to a packet data connection, the next amount of packet data to be sent is determined. If that amount exceeds the first threshold, the connection state is maintained. If the amount is less than the first threshold but greater than the second threshold, the connection state is also maintained. However, if the amount of data to be transmit is less than the second threshold, the connection state is changed to release the dedicated channel and to employ a shared channel.

Another example method for determining whether to switch from a dedicated radio channel to a shared radio channel is now described. After a last amount of data to be sent is transmitted, (e.g., the transmit queue is empty), a predefined time

period is monitored. If a new data packet is not received at the end of that predetermined time period, then the dedicated channel is released, and a new shared channel is allocated to the connection. The predefined time period may be determined based on one or more parameters including, for example, a number of available or idle channel resources which may include the number of idle base station receivers. If there is no idle base station receiver, a dedicated radio channel cannot be assigned. However, the connection can be assigned to a shared radio channel. Another factor that may be considered in a CDMA system is the number of idle spreading codes for downlink communications.

Reference is now made to the Connection State Adaptation routine (block 60) shown in Fig. 8. As set forth earlier, a connection state in this illustrative example includes a selected radio channel type and a selected mobility management scheme. A connection state is initially selected at connection setup based upon a packet data service requested (block 61). Thereafter, the packet arrival rate or packet density for the connection is measured and stored (block 62). The next packet arrival time for the connection is predicted based on the stored past packet arrival times (block 63). Alternatively, if packet density is the parameter employed, a future packet density is predicted based on past packet density determinations. Using the predicted packet arrival time (or predicted packet density), and possibly (but not necessarily) other parameter(s), an optimal type of radio channel is selected which still also fulfills the requested packet data service (block 64). Radio channel types include both dedicated and shared types of channels. In addition, shared radio channels include temporary dedicated channels, access channels, and paging channels. The optimal mobility management scheme best suited for the selected channel type may also be selected along with other parameters. For reasons described above, a cell update type of mobile management scheme is preferably selected for dedicated, temporarily-dedicated, and access radio channels. A routing area update type of mobility management scheme is preferably selected for paging channels (block 65). A decision is made in block 66

whether the connection has been disconnected. If not, the Connection State Adaptation procedures are repeated beginning at block 62.

Fig. 9 is a state diagram that illustrates the adaptive nature of connection state selection in accordance with this example embodiment where connection states are correlated with radio services. Initially, the connection state is "idle" before a packet data connection is established. When a packet data connection is initially set up by the radio access network, either upon request from a core network or the mobile station, one of the four active connection states is selected using parameter information from the requested data service, e.g., quality of service type parameters such as maximum and average bit rate, delay parameters, etc. All of such characteristics may be condensed into a "service vector" used to make the initial choice of connection state.

The four active connection states include (1) a dedicated radio service that employed a dedicated radio channel (DCH), (2) a shared radio service that employs a temporary DCH, (3) a shared radio service that employs forward access channels (FACH) and random access channels (RACH), and (4) a shared radio service that employs paging channels (PCH) and RACHs. Each connection state also specifies a corresponding mobility management scheme. The dedicated radio service employs handover as the mobility management scheme. The shared radio service using a temporary dedicated channel and the shared radio service for forward and random access channels both employ cell update mobility management schemes. However, the paging channel/random access channel shared radio service uses a routing area update mobility management scheme.

As packets are sent over the connection, the flow of packets is monitored and evaluated, and if appropriate, a new connection state is selected. Based on downlink (DL) packet flow measurements and uplink (UL) packet flow measurements, the radio access network may initiate a connection state change on either or both the downlink and the uplink. The mobile terminal may also initiate a connection state

transition based upon packet flow measurements on the uplink between the various shared radio services. When the connection is released by the core network, the radio access network, or the mobile terminal, the flow returns to the idle state.

Fig. 10 illustrates one example implementation in the mobile communications system of Fig. 2. A connection state selector (CSS) is provided in each radio network controller 26 (CSS_N 70) and each mobile station 30 (CSS_M 80). The radio network controller 26 also includes packet flow measurement units for both uplink and downlink directions corresponding to M_{ND} 72 and M_{NU} 74. Similarly, the mobile station 30 includes downlink and uplink packet flow measurement units M_{MD} 76 and M_{MU} 78. The uplink and downlink directions of the established connection are shown in bold lines. Connection queues 71 and 81 are provided in both the RNC and the mobile station which store current data packets to be sent over the connection. It is to be understood that a connection state selector may be placed in any network node in addition to each mobile station. However, locating the CSS in a base station rather than in the radio network controller may result in significant data shuffling between base stations when the mobile station changes cells to another base station, e.g., historical data for the connection. Since the radio network controller offers the packet data service to the core networks, it is preferable to locate the CSS in the RNC.

The measurement units in the mobile station and in the RNC measure the flow of packets (and other parameters if desired) in both uplink and/or downlink directions by storing packet arrival times which are then transferred to the respective connection state selectors 70 and 80. Rather than packet arrival times, packet density may be employed as the data flow parameter. Packet density may be a better parameter if the packet size is variable. When a connection state selector determines that a connection state change is necessary, it sends a signal to a corresponding controller, i.e., the RNC controller 75 or the mobile station controller 82. The respective controller

handles the signaling over the radio interface in order to make the connection state change.

Fig. 11 is a diagram which shows an example of downlink packet flow and the interaction between the network downlink measurement unit 72, the network connection state selector 70, and the RNC controller 75. At each packet arrival, the measurement unit 72 sends a downlink packet notification message to the connection state selector 70 containing the packet arrival time $t_i(k)$, a current amount of data $Q_i(k)$ in an incoming packet queue to be transmitted form the network to the mobile station corresponding to this connection, and a measured interference $I_i(k)$ associated with that packet (the uplink interference may, for example, be measured by the BS and sent regularly to the MS and RNC while the downlink interference may be measured by the MS and sent regularly to the RNC via the BS). The subscript i refers to an i^{th} connection, and k refers to the k^{th} packet. Therefore, $t_i(k)$ is the arrival time of packet k during the i^{th} connection. The time elapsed between the $k-1^{th}$ packet and the k^{th} packet during the i^{th} connection is indicated as $\Delta_i(k)$.

Based on the downlink packet identification messages corresponding to the three arrived example packets $P1-P3$, the network connection state selector 70 may decide to change connection state and sends a change connection state message to the RNC controller 75 with the next connection state. In the context of a CDMA system, if the new connection state is a dedicated radio channel or a temporary dedicated radio channel, the RNC controller allocates a spreading code to the connection and sends messages to the base station(s) currently handling the call as well as to the mobile station with appropriate change of connection state information. Similarly, the RNC controller notifies the mobile station and base station of the mobility management scheme.

Further example implementation details regarding prediction of next packet arrival time and connection state selection based thereon are provided in conjunction with Packet Arrival Time Prediction routine (block 100) shown in flowchart format in Fig. 12 and the function block diagram illustrating an example connection state selector shown in Fig. 13. In general, the connection state selector 120 for each connection state iteration, inputs a most recently received packet arrival time $t_i(k)$ and predicts in a non-linear fashion a next packet arrival time $\delta_i(k+1)$ using a non-linear predictor 124 (block 102). The predicted next packet arrival time is input into a comparator 122 after a corresponding delay 123 and compared with the most recent packet arrival time $t_i(k)$ to generate an error $\varepsilon_i(k)$ (block 104). The error $\varepsilon_i(k)$ is used to update the non-linear predictor parameters in such a way so as to minimize the error $\varepsilon_i(k)$ (block 106).

A selector 126 receives the predicted time to next packet arrival $\delta_i(k+1)$ from the non-linear predictor 124 and uses that prediction to determine a next connection state $C_i(k+1)$. Again, while the next connection state may be selected based simply on that parameter $\delta_i(k+1)$ alone, in a preferred example embodiment, the selector 126 takes into account one or more other parameters such as an amount of packets (queue length $Q_i(k)$) to be sent over the connection, a service vector $S_i(k)$, current radio interference $I_i(k)$, and/or the current connection state $C_i(k)$ (block 108).

Typically, a long queue suggests a dedicated channel or a temporary dedicated channel. A common channel is probably better suited for a short queue. A service vector requiring a high data rate and/or short delay indicates that a dedicated channel or a temporary dedicated channel is a better selection. A high radio interference value indicates that a dedicated channel most likely is preferred, as opposed to a temporary dedicated channel or common channel, because temporary dedicated and common channels generate greater interference than a dedicated channel. Still further,

an earlier predicted packet arrival time indicates selection of a dedicated channel -- even if the queue is short -- especially if the bearer service requires a short delay.

The non-linear predictor 124 preferably employs a neural network prediction and learning approach as shown in Fig. 14. Of course, other types of predictors could be used such as Kalman filter-based model, a fuzzy, self-learning based model, etc. Packet arrives times $t_i(k)$ are input to a delay line type shift register 130. The output of each delay D is sent onto a next delay stage as well as input to a summing block. The output of each summer Σ generates a time elapsed $\Delta_i(k)$ between two consecutive packets over the connection. When the connection i is established, k is set to zero as well as all of the inputs $t_i(0), \ldots t_i(-n+1)$, where n is the number of previous packets used to predict a future packet. Example values of n are 2, 3, or 4. Alternatively, initial non-zero packet arrival times $t_i(0), \ldots t_i(-n+1)$ may be set based upon statistically or otherwise empirically determined values. The initial connection state $C_i(0)$ is preferably set using a service vector S_i. For example, if S_i = "First Class," then $C_i(0) = DCH$; if S_i = "Business Class," then $C_i(0)$ = FACH/RACH; and if S_i = "Economy Class," then $C_i(0)$ = PCH/RACH.

When a new packet arrives at time $t_i(k)$, k is incremented by 1 and the memory delay blocks are simultaneously updated. The shift register 130 outputs corresponding elapsed times $\Delta_i(k), \ldots, \Delta_i(k-3)$. An error signal $\varepsilon_i(k)$ is generated by comparator 138 by determining the difference between $\Delta_i(k)$ and the previous predicted arrival time output from delay 136 corresponding to $\delta_i(k)$. The learning algorithm 134 is used to process the calculated error. Preferably, the learning scheme employs a standard recursive prediction error algorithm (RPEM) with a forgetting factor. However, other algorithms could be used such as recursive least squares (RLS). The parameters updated by the learning scheme 134 include a weight α for each

neuron on neural network predictor 132 as well as a scalar β (one for each input to the neuron) and a position γ (one for each neuron). The scalar β and position γ parameters are shown in Fig. 13 as a corresponding activation function g, where g is also a function of Δ. While the activation functions g are shown as sigmoids, they can also be Gaussians or any continuous function returning values between "0" and "1." A "1" means that the corresponding neuron is fully active, and a "0" means that the corresponding neuron is completely inactive.

In any event, the learning scheme looks at the deviation between the measured and predicted packet arrival times and tries to update the parameters of the activation functions so that this difference is reduced to the smallest value possible. The summed outputs of the weighted neuron outputs corresponds to the predicted next of packet arrival time $\delta_i(k+1)$. In Fig. 12, $\delta_i(k+1) = \alpha_1 g_1 + \alpha_2 g_2 + \alpha_3 g_3 + \alpha_4 g_4$. Functions of the form

$$\delta_i(k+1) = \alpha_1^i g_1^i\left(\Delta_i, \beta_1^i, \gamma_1^i\right) + \ldots + \alpha_4^i g_4^i\left(\Delta_i, \beta_4^i, \gamma_4^i\right),$$

may be built where $\Delta_k(k) = \Delta_i(k)\ldots,\Delta_i(k-3)$. The activation function g may be chosen in different ways, e.g., as a sigmoid:

$$g_j^i\left(\Delta_i, \beta_j^i, \gamma_j^i\right) = \frac{1}{1+e^{-\left(\beta_j^{iT}\Delta_i - \gamma_j^i\right)}},$$

where β_j^i may be a vector with four components such as

$$\beta_j^{iT}\Delta_i = \beta_j^i(1)\Delta_i(1) + \beta_j^i(2)\Delta_i(2) + \beta_j^i(3)\Delta_i(3) + \beta_j^i(4)\Delta_i(4).$$

Regarding the inputs to the selector 126, it may be assumed that the service vector $S_i(k)$ and the current connection $C_i(k)$ assume hard values. The other inputs may be described by soft values or fuzzy sets where the transition from being

true to being false is gradual, and the degree of which is characterized by what is sometimes referred to as a membership function. Consider the following example:

Input	Notation	Values (example)
Desired bearer service	S_i	Economy, Business, First
Current connection state	$C_i(k)$	DCH, TDCH, FACH/RACH, PCH/RACH
Predicted time to the next packet arrival	$\delta_i(k+1)$	Soon, Late
Radio interference	$I_i(k)$	Low, High
Current packet queue length	$Q_i(k)$	Short, Long

Output	Notation	Values (example)
Next connection state	$C_i(k+1)$	DCH, TDCH, FACH/RACH, PCH/RACH

The mapping from the inputs to the output may be described by a number of rules, e.g.,

1- if (S_i is Economy) and ($C_i(k)$ is DCH), then apply the following rules:

if ($Q_i(k)$ is Short), then $C_i(k+1)$ is FACH/RACH
if ($\delta_i(k+1)$ is Soon) and ($Q_i(k)$ is Long), then $C_i(k+1)$ is DCH
if ($\delta_i(k+1)$ is Late) and ($I_i(k)$ is Low) and ($Q_i(k)$ is Long), then $C_i(k+1)$ is DCH
if ($\delta_i(k+1)$ is Late) and ($I_i(k)$ is High) and ($Q_i(k)$ is Long), then $C_i(k+1)$ is DCH

2 - if (S_i is Business) and ($C_i(k)$ is FACH/RACH), then apply the following rules:

if ($\delta_i(k+1)$ is Soon) and ($Q_i(k)$ is Short), then $C_1(k+1)$ is FACH/RACH
if ($I_i(k)$ is Low) and ($Q_i(k)$ is Long), then $C_1(k+1)$ is TDCH
if ($\delta_i(k+1)$ is Soon) and ($I_i(k)$ is High) and ($Q_i(k)$ is Long), then $C_i(k+1)$ is DCH
if ($\delta_i(k+1)$ is Late) and ($Q_i(k)$ is Short), then $C_i(k+1)$ is PCH/RACH
if ($\delta_i(k+1)$ is Late) and ($I_i(k)$ is High) and ($Q_i(k)$ is Long), then $C_i(k+1)$ is DCH

3 - if (S_i is First) and ($C_i(k)$ is TDCH), then apply the following rules:

if ($I_i(k)$ is Low), then $C_i(k+1)$ is TDCH
if ($\delta_i(k+1)$ is Soon) and ($I_i(k)$ is High), then $C_i(k+1)$ is DCH
if ($\delta_i(k+1)$ is Late) and ($I_i(k)$ is High) and ($Q_i(k)$ is Short, then $C_i(k+1)$ is FACH/RACH
if ($\delta_i(k+1)$ is Late) and ($I_i(k)$ is High) and ($Q_{i(k)}$ is Long), then $C_i(k+1)$ is DCH

Because S_i can be assigned three different values and $C_i(k)$ four different values, there are twelve different combinations of these inputs, each of which is associated with a set of rules of the kind given above. However, only one of these sets will be active at one time, so the computational burden is moderate.

The just-described, example embodiment of the present invention selects the optimal channel and mobility management scheme for a packet-switched connection. As a result, radio channel resources (e.g., CDMA spreading codes), are optimally utilized. Dedicated channels are used only when necessary or efficient. Users that do not have strict delay requirements may be allocated common channels with scheduled and queued transport. On the other hand, dedicated channels may be selected even for low data rates or small amounts of data in high interference conditions in order to minimize further interference. Using the present invention, it is possible to predict future packet bursts and to use that prediction to, in appropriate situations, change a channel type (and other connection state parameters) from one channel type to another to carry a next burst of packets.

While the present invention has been described with respect to a particular embodiment, those skilled in the art will recognize that the present invention is not limited to the specific embodiments described and illustrated herein. Different formats, embodiments, and adaptations besides those shown and described as well as many modifications, variations, and equivalent arrangements may also be used to implement the invention. Therefore, while the present invention has been described in relation to its preferred embodiments, it is to be understood that this disclosure is only illustrative and exemplary of the present invention and is merely for the purposes of providing a full and enabling disclosure of the invention. Accordingly, it is intended that the invention be limited only by the spirit and scope of the claims appended hereto.

WHAT IS CLAIMED IS:

1. For use in packet data communications, a method comprising:

determining for a packet data communication a traffic parameter associated with the connection;

predicting a future value of the traffic parameter associated with the communication using the determined traffic parameter; and

dynamically selecting one characteristic of a channel from a plurality of channel characteristics for the packet data communication based on the predicted parameter.

2. The method in claim 1, wherein the traffic parameter is a packet flow parameter.

3. The method in claim 2, wherein the packet flow parameter is packet arrival time.

4. The method in claim 2, wherein the packet flow parameter is packet density.

5. The method in claim 1, wherein the channel characteristic is the type of channel and where different types of channels include a dedicated channel carrying packet data associated with one communicating device and a shared channel carrying packet data associated with more than one communicating device.

6. The method in claim 5, wherein the channels are radio channels, and wherein the shared radio channel type may be selected from a temporary dedicated radio channel, a forward access channel, a random access channel, and a paging channel.

7. The method in claim 1 as applied to a mobile communications system, further comprising:

dynamically selecting one of plural mobility management schemes suited to the selected channel characteristic.

8. The method in claim 7, wherein the plural mobility management schemes include a first handover scheme, a second scheme where a mobile station's location is monitored on an individual cell basis, and a third scheme where a mobile station's location is monitored on a routing area basis, where a routing area includes plural cells.

9. The method in claim 1, wherein the one characteristic is a bit rate.

10. The method in claim 1, wherein the traffic parameter is associated with the packet data communication used to predict a future amount of data to be transmitted associated with the communication, and wherein one channel characteristic is selected when the amount of data to be transmitted exceeds a first threshold and another channel characteristic is selected when the amount of data to be transmitted is less than the first threshold.

11. The method in claim 10, further comprising:

providing a second threshold less then the first threshold,

wherein the other channel characteristic is selected when the amount of data to be transmitted is less than or equal to the second threshold.

12. The method in claim 10, further comprising:

considering at least one other traffic parameter in addition to the amount of data to be transmitted in selecting the channel characteristic.

13. The method in claim 12, wherein the one other traffic parameter is one of the following: number of channels of each type currently available, a specified quality of service, a current interference level, and a number of available radio channel resources.

14. The method in claim 12, further comprising:

measuring interference in one or both of uplink and downlink directions.

15. For use in a communications system that provides plural communication services, a method comprising the steps of:

determining for a packet data connection, a packet data parameter;

predicting a packet data parameter using the determined packet data parameter; and

dynamically selecting one connection state from a plurality of connection states for the packet data connection based on the predicted packet parameter.

16. The method in claim 15, wherein the packet parameter is a packet flow parameter.

17. The method in claim 16, wherein the packet flow parameter is packet arrival time.

18. The method in claim 16, wherein the packet flow parameter is packet density.

19. The method in claim 15, wherein each connection state specifies one of different types of radio services as applied to mobile radio communications services, each service specifying a type of channel and a mobility management scheme for keeping track of a location of a mobile station.

20. The method in claim 19, wherein each service also specifies a bit rate.

21. The method in claim 19, wherein the radio services include a dedicated radio service where service is provided exclusively for one mobile station and a shared radio service where service is shared with more than one mobile station.

22. The method in claim 21, wherein the dedicated radio service includes a reserved dedicated radio channel and the shared radio service includes one of: a temporary dedicated radio channel, a forward access channel, a random access channel, and a paging channel.

23. The method in claim 22, wherein the mobility management scheme includes a first handover scheme, a second scheme where a mobile station's location is monitored on an individual cell basis, and a third scheme where a mobile station's location is monitored on a routing area basis, where a routing area includes plural cells.

24. The method in claim 15, further comprising:

dynamically selecting another of the connection states for the packet data connection based on a change in the predicted packet parameter during the packet data connection.

25. The method in claim 15, wherein the packet data parameter is an amount of data to be transmitted associated with the packet data connection used to predict a future amount of data to be transmitted associated with the connection, and wherein one connection state is selected when the amount of data to be transmitted exceeds a first threshold and another connection state is selected when the amount of data to be transmitted is less the first threshold.

26. The method in claim 25, further comprising:

providing a second threshold less than the first threshold, wherein the other connection state is selected when the amount of data to be transmitted is less than or equal to the second threshold.

27. The method in claim 25, further comprising:

considering at least one other traffic parameter in addition to the amount of data to be transmitted in selecting the connection state.

28. The method in claim 25, wherein the considered other parameter is one of the following: number of channels of each type currently available, a specified quality of service, and a current interference level, and a number of available radio channel resources.

29. In a mobile communications system permitting selective communications with mobile stations, a controller comprising:

a connection state selector establishing a packet data connection with a mobile station at an initial connection state, and

a predictor predicting a time to a next packet arrival over the packet data connection using the packet arrival times of n most recent data packet arrival times over the connection,

wherein the connection state selector determines a next connection state based on the predicted next data packet arrival time.

30. The controller in claim 29, wherein the connection state selector determines the next connection state also based on one or more of the following: a desired bearer service, a current connection state, current radio interference, and a current packet queue length in a queue associated with the connection.

31. The controller in claim 29, wherein the predictor is a non-linear predictor receiving packet arrival times of plural packets over the connection.

32. The controller in claim 31, wherein the non-linear predictor is a neural network, the controller further comprising:

a comparator comparing a current packet arrival time to a corresponding predicted packet arrival time to determine an error, and

an adapter adapting neural network parameters to reduce the error.

33. The controller in claim 32, wherein the neural network adapter employs a recursive prediction error algorithm with a forgetting factor.

34. The controller in claim 32, wherein the neural network receives as inputs elapsed times between packet arriving over the connection.

35. The controller in claim 31, wherein the next connection state specifies one of different type radio services, each service specifying a type of channel and a mobility management scheme for keeping track of a location of a mobile station.

36. The controller in claim 31, wherein the radio services include a dedicated radio service where service is provided exclusively for one mobile user and a shared radio service where service is shared with more than one mobile user.

37. The controller in claim 31, wherein the shared radio service includes: a temporary dedicated radio channel, a forward access channel, a random access channel, and a paging channel.

38. The controller in claim 31, wherein the mobility management scheme includes a first handover scheme, a second scheme where a mobile station's location is monitored on an individual cell basis, and a third scheme where a mobile station's location is monitored on a routing area basis, where a routing area includes plural cells.

39. The controller in claim 31, wherein the connection state selector selects another of connection states for the packet data connection based on a change in the predicted next data packet arrival time during the packet data connection.

40. The controller in claim 29, wherein the packet data parameter is an amount of data to be transmitted associated with the packet data connection used to predict a future amount of data to be transmitted associated with the connection, and wherein one type of channel is selected when the amount of data to be transmitted exceeds a threshold and another type of channel is selected when the amount of data to be transmitted is less than or equal the threshold.

41. The controller in claim 40, wherein the connection state selector considers at least one other traffic parameter in addition to amount of data to be transmitted in selecting the type of channel.

42. The controller in claim 41, wherein the one other parameter is one of the following: number of channels of each type currently available, a specified quality of service, and a current interference level.

43. The controller in claim 29 as employed in a mobile station.

44. The controller in claim 29 as employed in a communications network controller.

45. For use in a mobile communications system supporting a packet data connection with a mobile station, a method comprising:

determining for the packet data connection an amount of packet data to be sent;

comparing the determined amount to a threshold;

if the determined amount exceeds the threshold, deciding to allocate the packet data connection to a dedicated radio channel; and

if the determined amount is less than the threshold, deciding to allocate the packet data connection to a shared radio channel.

46. The method in claim 45, further comprising:

considering at least one other parameter in addition to the amount of packet data to be sent in selecting the type of channel, and

allocating the packet data connection to one of the dedicated and shared radio channels based on the threshold decision and the considered other parameter.

47. The method in claim 46, wherein the considered other parameter is one of the following: number of channels of each type currently available, a specified quality

of service, a current interference level, and a number of available radio channel resources.

48. The method in claim 45, further comprising:

determining the packet data connection an amount of packet data to be sent on both the uplink direction for packet data to be transmitted from the mobile station and the downlink direction for packet data to be received by the mobile station,

wherein different ones of the dedicated and shared radio channels may be allocated to the uplink and downlink directions.

49. The method in claim 45, wherein if the shared channel is initially decided, the method further comprises:

selecting one of plural different types of shared radio channels based on the determined amount of packet data to be sent.

50. The method in claim 45, wherein after a dedicated radio channels is allocated to the packet data connection, the method further comprises:

determining for the packet data connection a next amount of packet data to be sent,

releasing the allocated dedicated radio channel if the next amount of packet data is less than the threshold.

51. The method in claim 50, further comprising:

after the releasing, allocating a shared radio channel to the packet data connection.

52. The method in claim 45, wherein after a dedicated radio channels is allocated to the packet data connection, the method further comprises:

waiting a predefined time period for an amount of packet data to be sent; and

releasing the allocated dedicated radio channel if a new data packet is not received within the predefined time period.

53. The method in claim 52, wherein the predefined time period is determined based on one or more of the following:

a number of available channel resources, interference, and battery capacity of the mobile station.

54. The method in claim 52, further comprising:

after the releasing, allocating a shared radio channel to the packet data connection.

55. For use in a communications system supporting a packet data connection with a mobile station over a radio access network, a method comprising:

determining for the packet data connection an amount of packet data to be sent;

comparing the determined amount of packet data to an amount threshold;

if the determined amount exceeds the amount threshold, determining whether the packet data connection is disconnected or interrupted, and if not, establishing the packet data connection on or transferring the packet data connection to a dedicated radio channel; and

if the determined amount of packet data is less than the amount threshold, considering at least one other factor in deciding what type of radio channel should bear the packet data connection.

56. The method in claim 55, wherein if the amount of packet data exceeds the amount threshold and if the packet data connection is determined to be temporarily disconnected or interrupted, the method further comprising:

maintaining the packet data connection on the radio channel currently bearing the packet data connection.

57. The method in claim 55, further comprising:

if the determined amount of packet data exceeds the first amount threshold and if the packet data connection is determined to be temporarily disconnected or interrupted, the method further comprising:

deciding that the packet data connection should not be transferred to a dedicated radio channel.

58. The method in claim 55, wherein the one other factor relates to a flow of packets over the packet data connection, the method further comprising:

if the determined amount of packet data is less than or equal to the first amount threshold and if the flow of packets exceeds a flow threshold, allocating the packet data connection to a dedicated radio channel.

59. The method in claim 58, the method further comprising:

if the determined amount of packet data is less than or equal to the first amount threshold and if the flow of packets is less than or equal to a flow threshold, allocating the packet data connection to a shared radio channel.

60. The method in claim 59, further comprising:

adding hysteresis to the allocating steps.

61. The method in claim 55, wherein the one other factor is a time interval between packets, the method further comprising:

determining time intervals between packets over the packet data connection; and

when the determined time intervals between packets are similar, deciding to assign the packet data connection to a dedicated radio channel.

62. The method in claim 55, wherein the one other factor is whether the amount of packet data is increasing or decreasing when the amount of packet data is determined to be less than a threshold.

63. For use in a communications system supporting a packet data connection with a mobile station over a radio access network, a method comprising the steps of:

(a) determining for the packet data connection an amount of packet data to be sent;

(b) comparing the determined amount of packet data to a first amount threshold;

(c) if the determined amount exceeds the first amount threshold, comparing the determined amount of packet data to a second amount threshold;

(d) establishing the packet data connection on or transferring the packet data connection to one of a dedicated radio channel and a common radio channel based on comparisons made in steps (b) and (c).

64. The method in claim 63, further comprising:

if the determined amount of packet data is less than the first amount threshold, considering at least one other parameter in deciding what type of radio channel should bear the packet data connection.

65. The method in claim 63, further comprising:

if the determined amount of packet data is less than the first amount threshold, selecting a common channel to bear the packet data connection.

66. The method in claim 63, further comprising:

if the determined amount of packet data is less than the first amount threshold, determining if a back pressure condition exists;

if a back pressure condition does not exist, selecting a common radio channel to bear the packet data connection.

67. The method in claim 66, further comprising:

if a back pressure condition does not exist, selecting a radio channel type to bear the packet data connection in accordance with a secondary channel type selection procedure.

68. The method in claim 66, further comprising:

if a back pressure condition does exist, selecting a dedicated radio channel to bear the packet data connection.

69. The method in claim 66, further comprising:

if a back pressure condition does exist, maintaining a current radio channel to bear the packet data connection.

70. The method in claim 63, further comprising:

if the determined amount of packet data exceeds the second threshold, establishing the packet data connection on or transferring the packet data connection to a dedicated radio channel.

71. The method in claim 63, further comprising:

if the determined amount of packet data exceeds the second threshold, determining if data are not currently being transmit over the packet data connection.

72. The method in claim 71, wherein if data are not currently being transmit over the packet data connection, the method further comprising:

maintaining the packet data connection on the radio channel currently bearing the packet data connection.

73. The method in claim 71, wherein if data are currently being transmit over the packet data connection, the method further comprising:

selecting a dedicated radio channel to bear the packet data connection.

74. The method in claim 63, further comprising:

if the determined amount of packet data is greater than the first amount threshold and less than the second amount threshold, employing hysteresis when selecting the type of radio channel to bear the packet data connection.

75. The method in claim 74, further comprising:

determining whether the determined amount of packet data decreased from being greater than the second amount threshold to being less than the second amount threshold, and if so, selecting a dedicated radio channel to bear the packet data connection.

76. The method in claim 75, wherein if determined amount of packet data increased from being less than the first amount threshold to being greater than the first amount threshold, the method further comprising:

selecting a common radio channel to bear the packet data connection.

77. The method in claim 75, wherein if determined amount of packet data increased from being less than the first amount threshold to being greater than the first amount threshold, the method further comprising:

selecting a type of radio channel to bear the packet data connection using a secondary channel type selection procedure.

78. In a communications system permitting selective communications with mobile stations by way of a radio access network, apparatus comprising:

a connection state controller controlling a packet data connection with a mobile station to deliver packets to a mobile station,

a packet buffer storing packets to be sent over the packet data connection, and

wherein the connection state controller selects a higher capacity type of radio channel to bear the packet data connection or a lower capacity type of radio channel to

bear the packet data connection based on the amount of data currently stored in the packet buffer.

79. The apparatus in claim 78, wherein the connection state controller compares the amount of packet data in the packet buffer to a first threshold and a second threshold greater than the first threshold.

80. The apparatus in claim 79, wherein if the amount of packet data in the packet buffer is less than both the first threshold and the second threshold, the connection state controller selects the lower capacity radio channel.

81. The apparatus in claim 79, wherein if the amount of packet data is greater than the first threshold and greater than the second threshold, the connection state controller maintains the packet data connection on a current type of radio channel.

82. The apparatus in claim 79, wherein if the amount of packet data is greater than the first and second thresholds, the connection state controller selects a higher capacity radio channel to carry the packet data connection.

83. The apparatus in claim 79, wherein if the amount of packet data in the packet buffer is greater than or equal to the first threshold and less than the second threshold, the connection state controller determines the type of radio channel taking into account at least one additional parameter.

84. The apparatus in claim 79, wherein if the amount of packet data in the packet buffer is greater than the first threshold and less than the second threshold, the connection state controller selects a higher capacity radio channel to carry the packet data connection.

85. The apparatus in claim 79, wherein if the amount of packet data in the packet buffer is greater than the first threshold and less than the second threshold, the

connection state controller selects a lower capacity radio channel to carry the packet data connection.

86. The apparatus in claim 78, further comprising:

a packet store providing packets to the packet buffer,

wherein when an amount of packets currently stored the packet buffer exceeds a predetermined percentage of the packet buffer size, the packet buffer generates a back pressure signal used to instruct the packet store to temporarily halt transmission of packets to the packet buffer.

87. The apparatus in claim 86, wherein the connection state controller compares the amount of packet data in the packet buffer to a first threshold, and if the amount of packet data in the packet buffer is less than the first threshold and if the back pressure signal is not present, the connection state controller selects the lower capacity type of radio channel.

88. The apparatus in claim 86, wherein the connection state controller compares the amount of packet data in the packet buffer to a first threshold, and if the amount of packet data in the packet buffer is less than the first threshold and if the back pressure signal is not present, the connection state determines the radio channel type using an additional parameter relating to packet flow.

89. The apparatus in claim 88, wherein the additional parameter is traffic intensity.

90. The apparatus in claim 88, wherein the additional parameter is time between packet arrivals.

91. The apparatus in claim 86, wherein the connection state controller compares the amount of packet data in the packet buffer to a first threshold, and if the amount of packet data in the packet buffer is less than the first threshold and if the back

pressure signal is present, the connection state controller selects the higher capacity type of radio channel.

92. The apparatus in claim 78, further comprising:

a protocol sending window buffer used to monitor packets transmitted from the packet buffer but not yet acknowledged as received, the protocol window buffer generating a full window signal when the number of not yet acknowledged packets exceeds a predetermined threshold.

93. The apparatus in claim 90, wherein if the amount of packet data in the packet buffer is less than a first threshold and if the full window signal is not present, the connection state controller selects the higher capacity type of radio channel to bear the packet data connection.

94. The apparatus in claim 90, wherein if the amount of packet data in the packet buffer is less than a first threshold and if the full window signal is present, the connection state controller maintains the radio channel type currently being used to bear the packet data connection.

95. The apparatus in claim 90, wherein if the amount of packet data in the packet buffer is greater than a first threshold and a second larger threshold, and if the full window signal is present, the connection state controller maintains a current type of radio channel to bear the packet data connection.

96. The apparatus in claim 79, wherein if the determined amount of packet data is greater than the first threshold and less than the second threshold, the connection state controller employs hysteresis when selecting the type of radio channel to bear the packet data connection.

97. The apparatus in claim 96, wherein the connection state controller determines whether the determined amount of packet data decreased from being greater

than the second amount threshold, and if so, the connection state controller selects a higher capacity radio channel to bear the packet data connection.

98. The apparatus in claim 96, wherein the connection state controller determines whether the amount of packet data increased from being less than the first amount threshold, and if so, the connection state controller selects a lower capacity radio channel to bear the packet data connection.

99. The apparatus in claim 96, wherein the connection state controller determines whether the amount of packet data increased from being less than the first amount threshold, and if so, the connection state controller selects a type of radio channel to bear the packet data connection using a secondary channel type selection procedure.

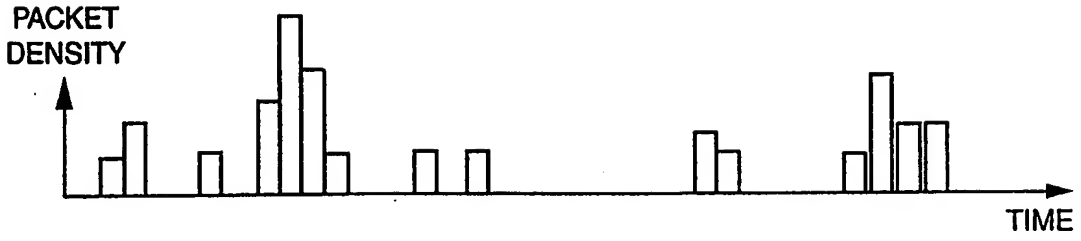

PACKET
DENSITY
TIME

Fig. 1

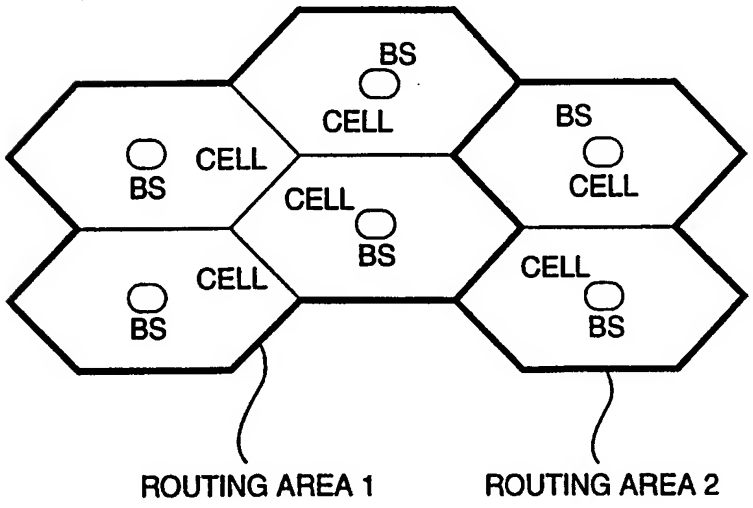

BS
CELL
BS
CELL
BS
CELL
CELL
BS
CELL
BS
CELL
BS
ROUTING AREA 1
ROUTING AREA 2

Fig. 3

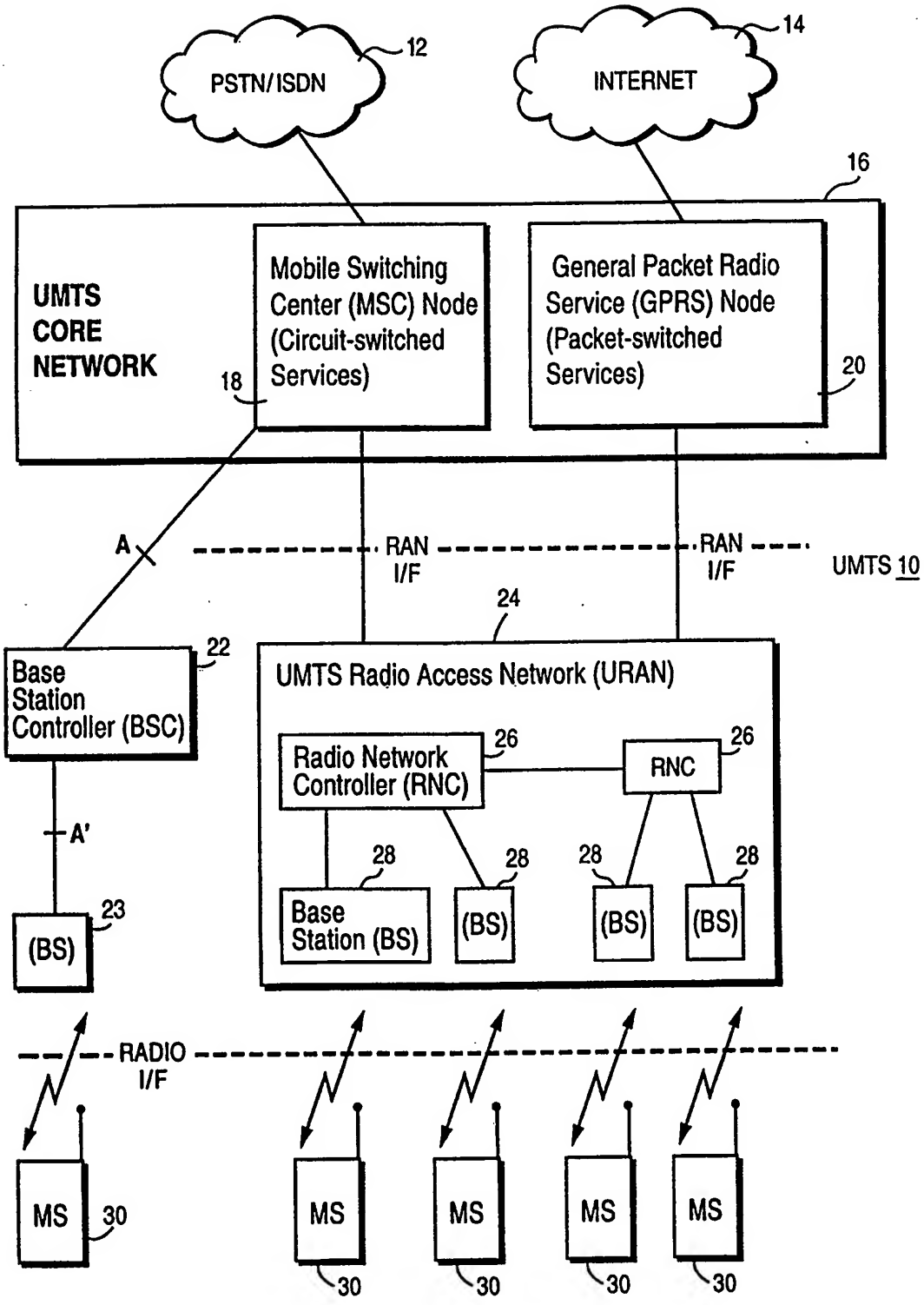

PSTN/ISDN
12
INTERNET
14
16
UMTS CORE NETWORK
Mobile Switching Center (MSC) Node (Circuit-switched Services)
18
General Packet Radio Service (GPRS) Node (Packet-switched Services)
20
A
RAN I/F
RAN I/F
UMTS 10
24
Base Station Controller (BSC)
22
UMTS Radio Access Network (URAN)
Radio Network Controller (RNC)
26
RNC
26
A'
28
28
28
28
Base Station (BS)
(BS)
(BS)
(BS)
(BS)
23
RADIO I/F
MS
30
MS
MS
MS
MS
30
30
30
30

Fig. 2

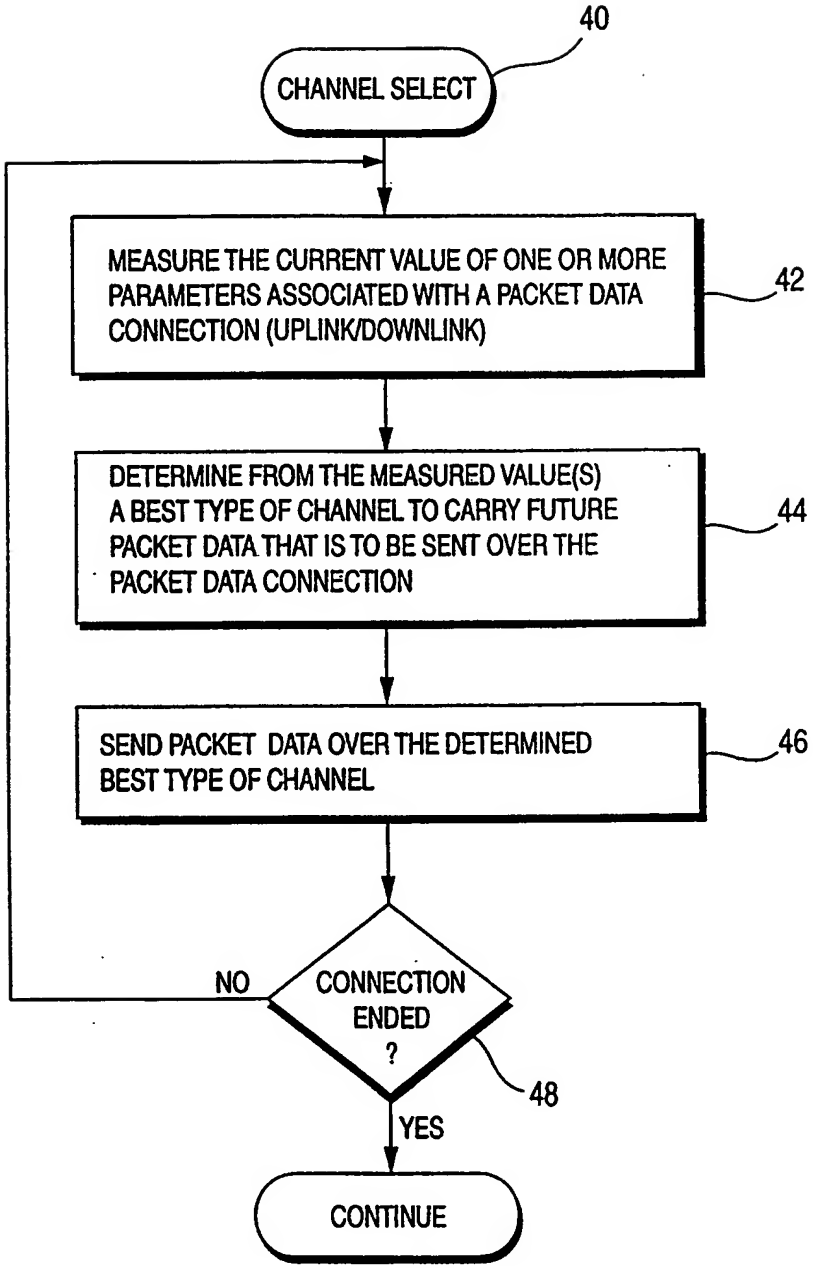

40
CHANNEL SELECT
MEASURE THE CURRENT VALUE OF ONE OR MORE PARAMETERS ASSOCIATED WITH A PACKET DATA CONNECTION (UPLINK/DOWNLINK)
42
DETERMINE FROM THE MEASURED VALUE(S) A BEST TYPE OF CHANNEL TO CARRY FUTURE PACKET DATA THAT IS TO BE SENT OVER THE PACKET DATA CONNECTION
44
SEND PACKET DATA OVER THE DETERMINED BEST TYPE OF CHANNEL
46
NO
CONNECTION ENDED ?
48
YES
CONTINUE

Fig. 4

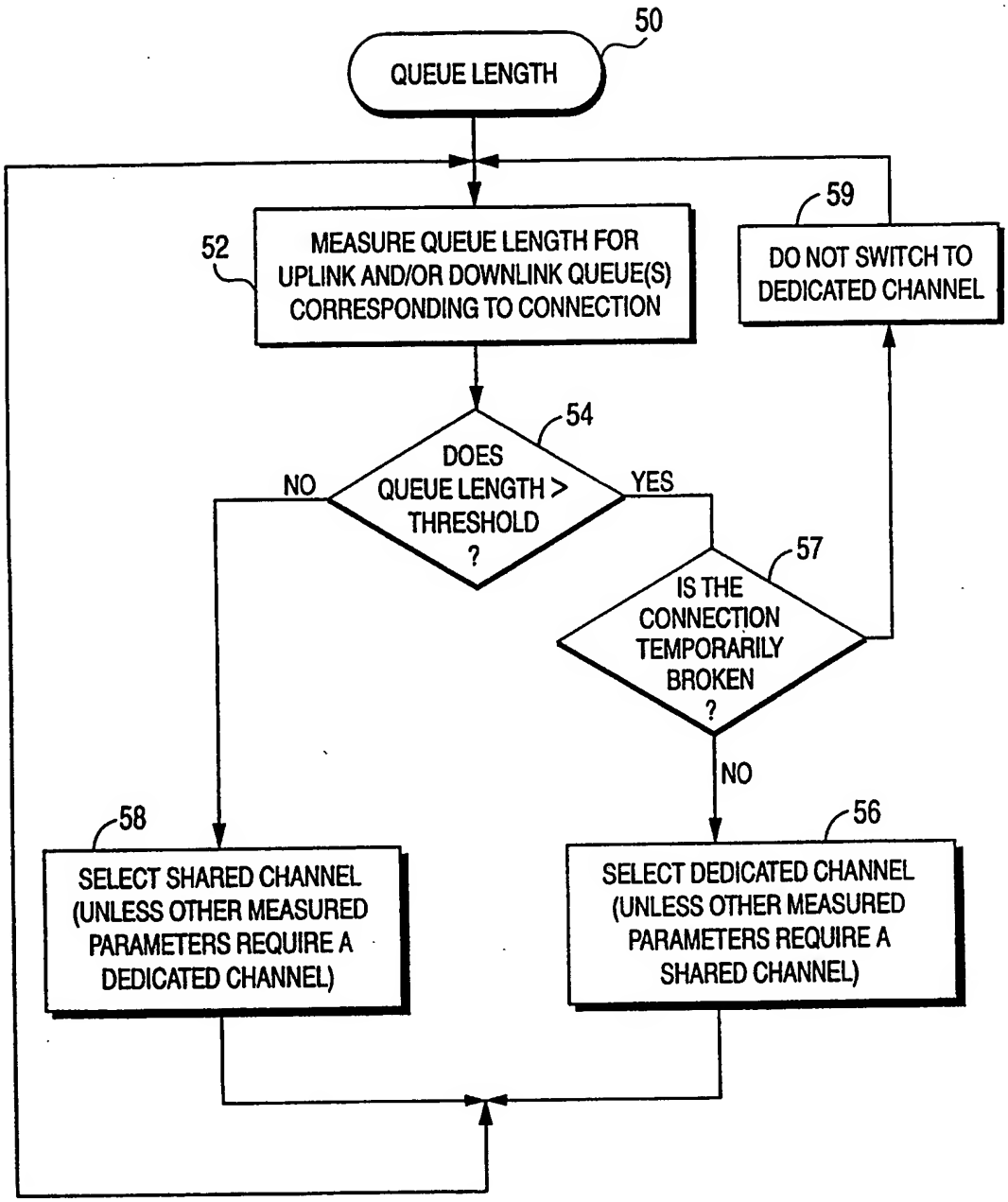

50
QUEUE LENGTH
52
MEASURE QUEUE LENGTH FOR UPLINK AND/OR DOWNLINK QUEUE(S) CORRESPONDING TO CONNECTION
59
DO NOT SWITCH TO DEDICATED CHANNEL
54
DOES QUEUE LENGTH > THRESHOLD ?
NO
YES
57
IS THE CONNECTION TEMPORARILY BROKEN ?
NO
58
SELECT SHARED CHANNEL (UNLESS OTHER MEASURED PARAMETERS REQUIRE A DEDICATED CHANNEL)
56
SELECT DEDICATED CHANNEL (UNLESS OTHER MEASURED PARAMETERS REQUIRE A SHARED CHANNEL)

Fig. 5

Fig. 6

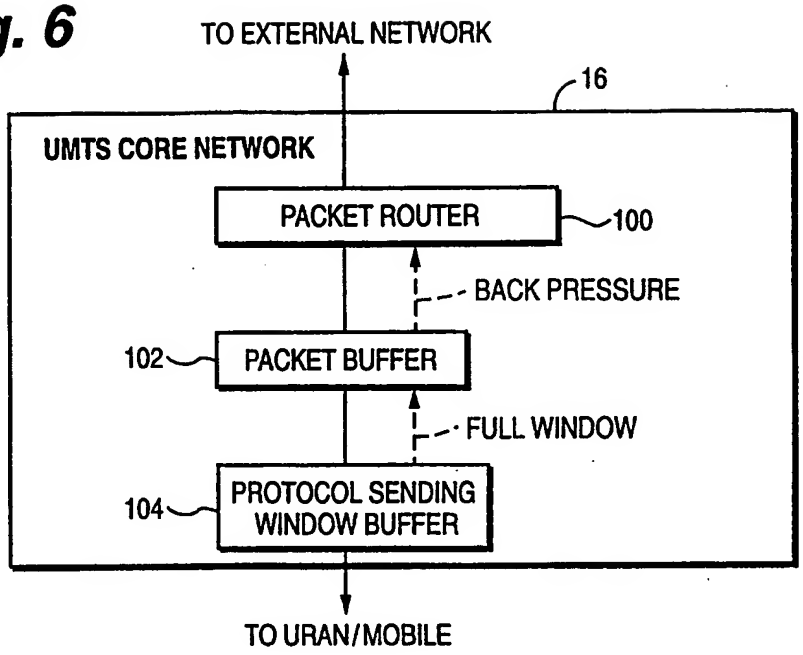

TO EXTERNAL NETWORK
16
UMTS CORE NETWORK
PACKET ROUTER
100
BACK PRESSURE
102
PACKET BUFFER
FULL WINDOW
104
PROTOCOL SENDING WINDOW BUFFER
TO URAN/MOBILE

Fig. 9

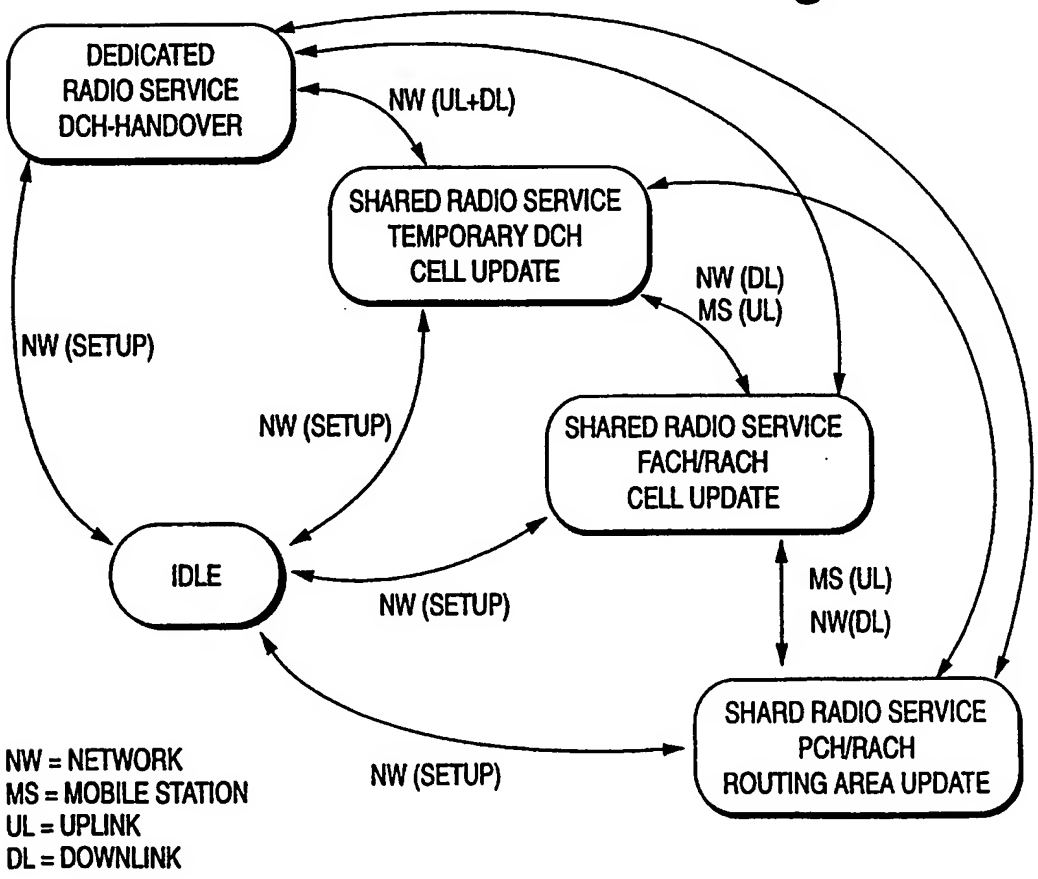

DEDICATED RADIO SERVICE DCH-HANDOVER
NW (UL+DL)
SHARED RADIO SERVICE TEMPORARY DCH CELL UPDATE
NW (DL) MS (UL)
NW (SETUP)
NW (SETUP)
SHARED RADIO SERVICE FACH/RACH CELL UPDATE
IDLE
NW (SETUP)
MS (UL) NW(DL)
SHARD RADIO SERVICE PCH/RACH ROUTING AREA UPDATE
NW (SETUP)
NW = NETWORK
MS = MOBILE STATION
UL = UPLINK
DL = DOWNLINK

Fig. 7

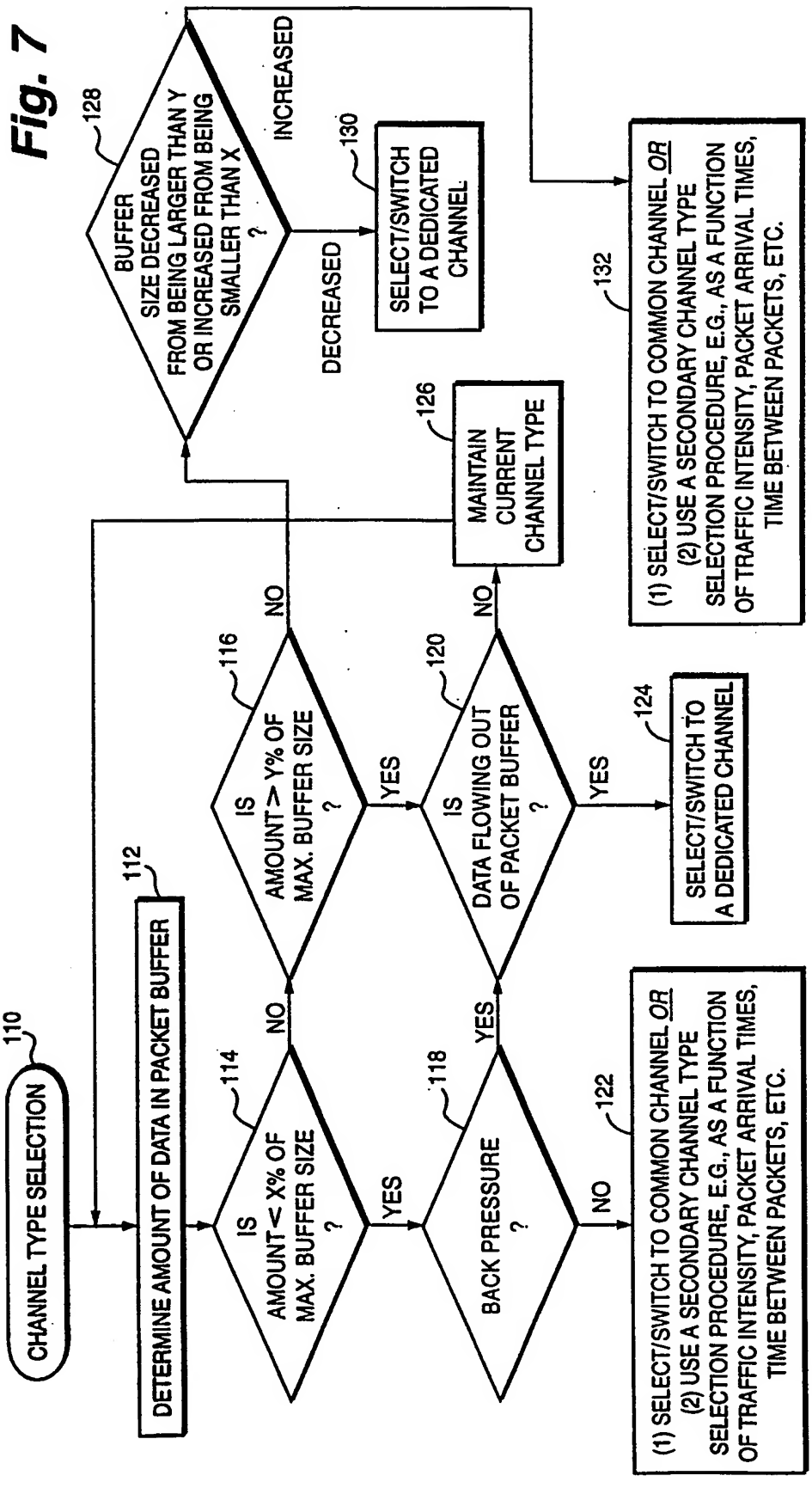
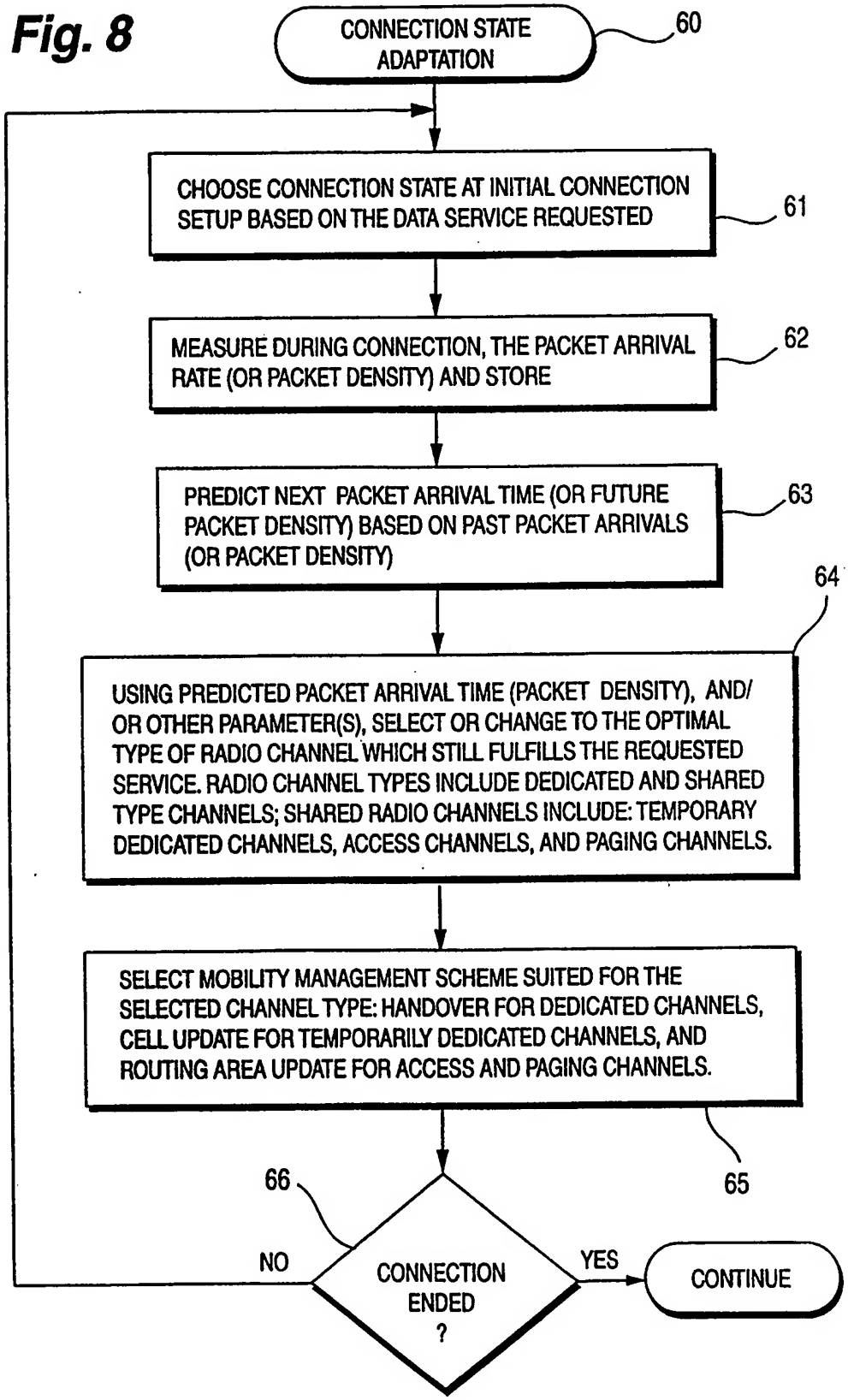

110
CHANNEL TYPE SELECTION
112
DETERMINE AMOUNT OF DATA IN PACKET BUFFER
114
IS AMOUNT < X% OF MAX. BUFFER SIZE ?
NO
YES
116
IS AMOUNT > Y% OF MAX. BUFFER SIZE ?
NO
YES
118
BACK PRESSURE ?
YES
NO
120
IS DATA FLOWING OUT OF PACKET BUFFER ?
NO
YES
122
(1) SELECT/SWITCH TO COMMON CHANNEL OR (2) USE A SECONDARY CHANNEL TYPE SELECTION PROCEDURE, E.G., AS A FUNCTION OF TRAFFIC INTENSITY, PACKET ARRIVAL TIMES, TIME BETWEEN PACKETS, ETC.
124
SELECT/SWITCH TO A DEDICATED CHANNEL
126
MAINTAIN CURRENT CHANNEL TYPE
128
BUFFER SIZE DECREASED FROM BEING LARGER THAN Y OR INCREASED FROM BEING SMALLER THAN X ?
DECREASED
INCREASED
130
SELECT/SWITCH TO A DEDICATED CHANNEL
132
(1) SELECT/SWITCH TO COMMON CHANNEL OR (2) USE A SECONDARY CHANNEL TYPE SELECTION PROCEDURE, E.G., AS A FUNCTION OF TRAFFIC INTENSITY, PACKET ARRIVAL TIMES, TIME BETWEEN PACKETS, ETC.

Fig. 8


CONNECTION STATE ADAPTATION
60
CHOOSE CONNECTION STATE AT INITIAL CONNECTION SETUP BASED ON THE DATA SERVICE REQUESTED
61
MEASURE DURING CONNECTION, THE PACKET ARRIVAL RATE (OR PACKET DENSITY) AND STORE
62
PREDICT NEXT PACKET ARRIVAL TIME (OR FUTURE PACKET DENSITY) BASED ON PAST PACKET ARRIVALS (OR PACKET DENSITY)
63
64
USING PREDICTED PACKET ARRIVAL TIME (PACKET DENSITY), AND/ OR OTHER PARAMETER(S), SELECT OR CHANGE TO THE OPTIMAL TYPE OF RADIO CHANNEL WHICH STILL FULFILLS THE REQUESTED SERVICE. RADIO CHANNEL TYPES INCLUDE DEDICATED AND SHARED TYPE CHANNELS; SHARED RADIO CHANNELS INCLUDE: TEMPORARY DEDICATED CHANNELS, ACCESS CHANNELS, AND PAGING CHANNELS.
SELECT MOBILITY MANAGEMENT SCHEME SUITED FOR THE SELECTED CHANNEL TYPE: HANDOVER FOR DEDICATED CHANNELS, CELL UPDATE FOR TEMPORARILY DEDICATED CHANNELS, AND ROUTING AREA UPDATE FOR ACCESS AND PAGING CHANNELS.
65
66
NO
CONNECTION ENDED ?
YES
CONTINUE

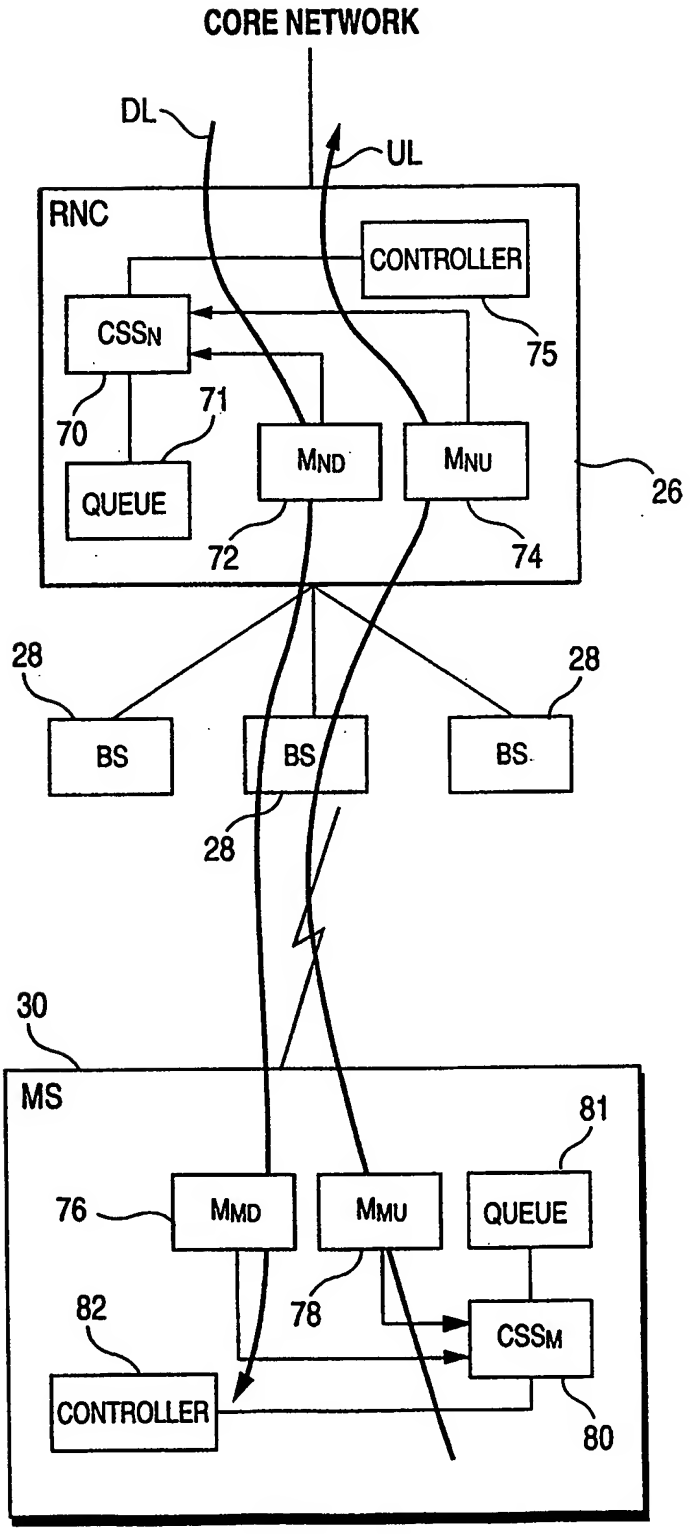

CORE NETWORK
DL
UL
RNC
CONTROLLER
CSSN
75
71
70
MND
MNU
26
QUEUE
72
74
28
28
BS
BS
BS
28
30
MS
81
76
MMD
MMU
QUEUE
82
78
CSSM
CONTROLLER
80

Fig. 10

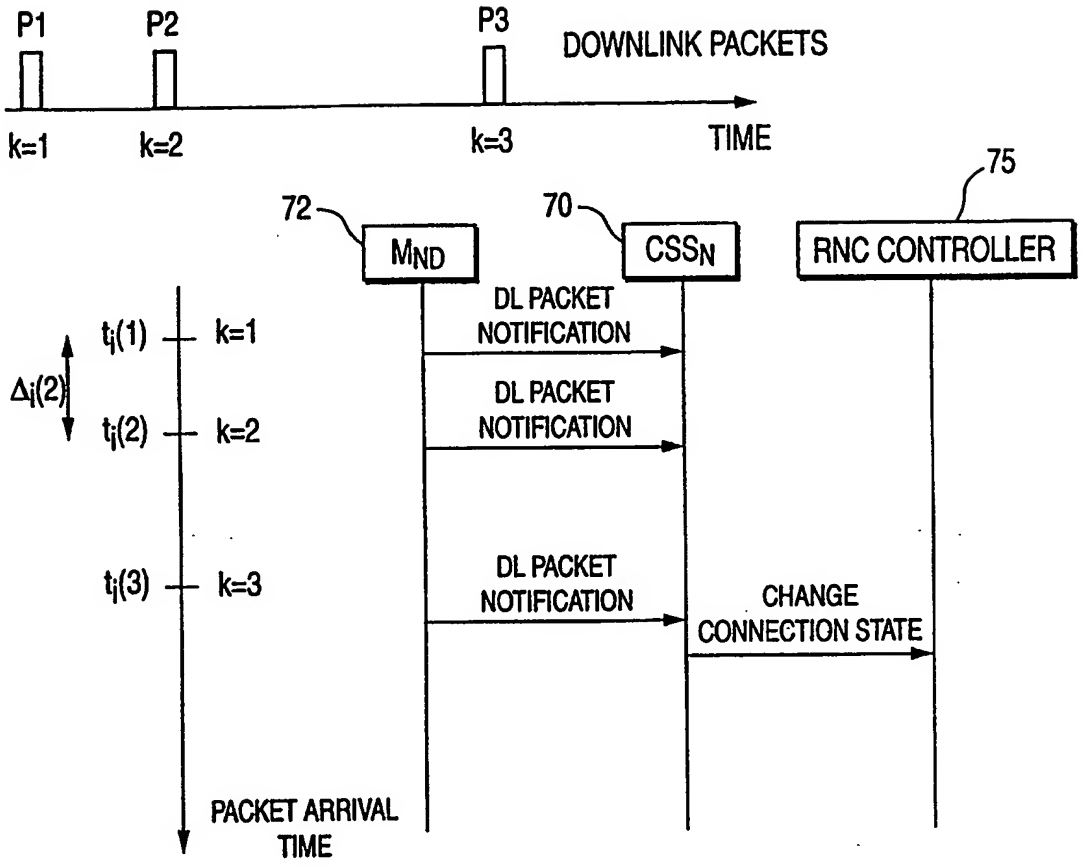

P1
P2
P3
DOWNLINK PACKETS
k=1
k=2
k=3
TIME
75
72
70
MND
CSSN
RNC CONTROLLER
DL PACKET NOTIFICATION
DL PACKET NOTIFICATION
DL PACKET NOTIFICATION
CHANGE CONNECTION STATE
ti(1)
k=1
Δi(2)
ti(2)
k=2
ti(3)
k=3
PACKET ARRIVAL TIME

Fig. 11

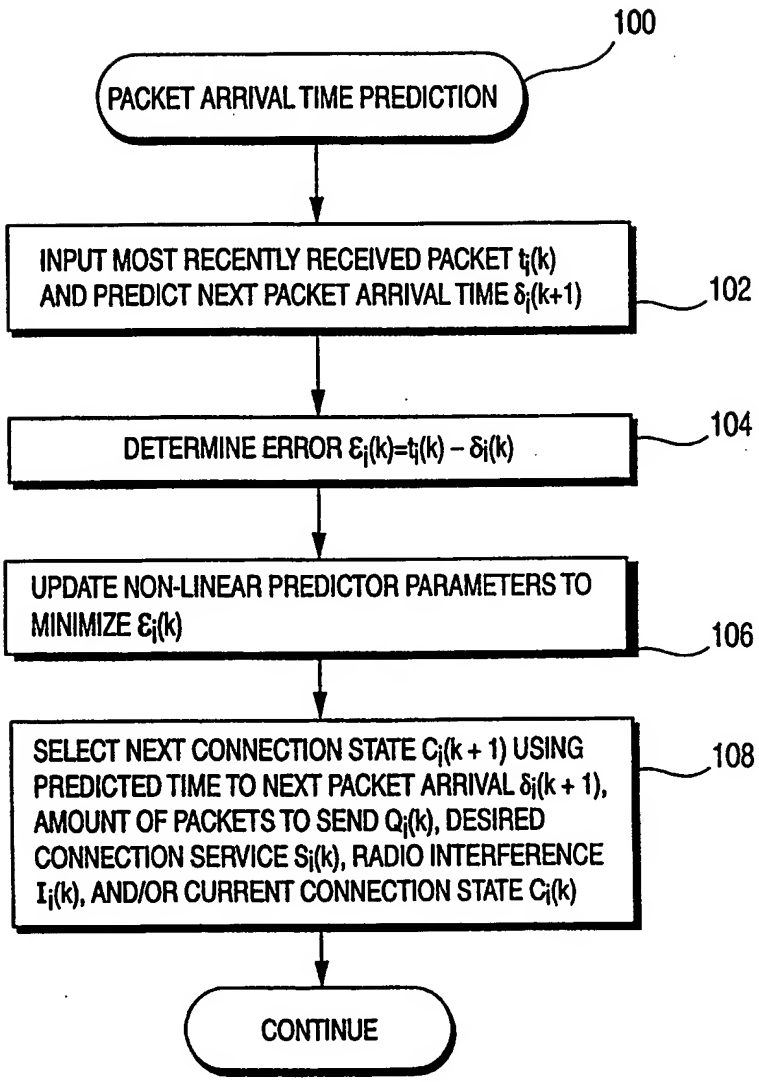

100
PACKET ARRIVAL TIME PREDICTION
INPUT MOST RECENTLY RECEIVED PACKET $t_i(k)$ AND PREDICT NEXT PACKET ARRIVAL TIME $\delta_i(k+1)$
102
DETERMINE ERROR $\varepsilon_i(k)=t_i(k)-\delta_i(k)$
104
UPDATE NON-LINEAR PREDICTOR PARAMETERS TO MINIMIZE $\varepsilon_i(k)$
106
SELECT NEXT CONNECTION STATE $C_i(k+1)$ USING PREDICTED TIME TO NEXT PACKET ARRIVAL $\delta_i(k+1)$, AMOUNT OF PACKETS TO SEND $Q_i(k)$, DESIRED CONNECTION SERVICE $S_i(k)$, RADIO INTERFERENCE $I_i(k)$, AND/OR CURRENT CONNECTION STATE $C_i(k)$
108
CONTINUE

Fig. 12

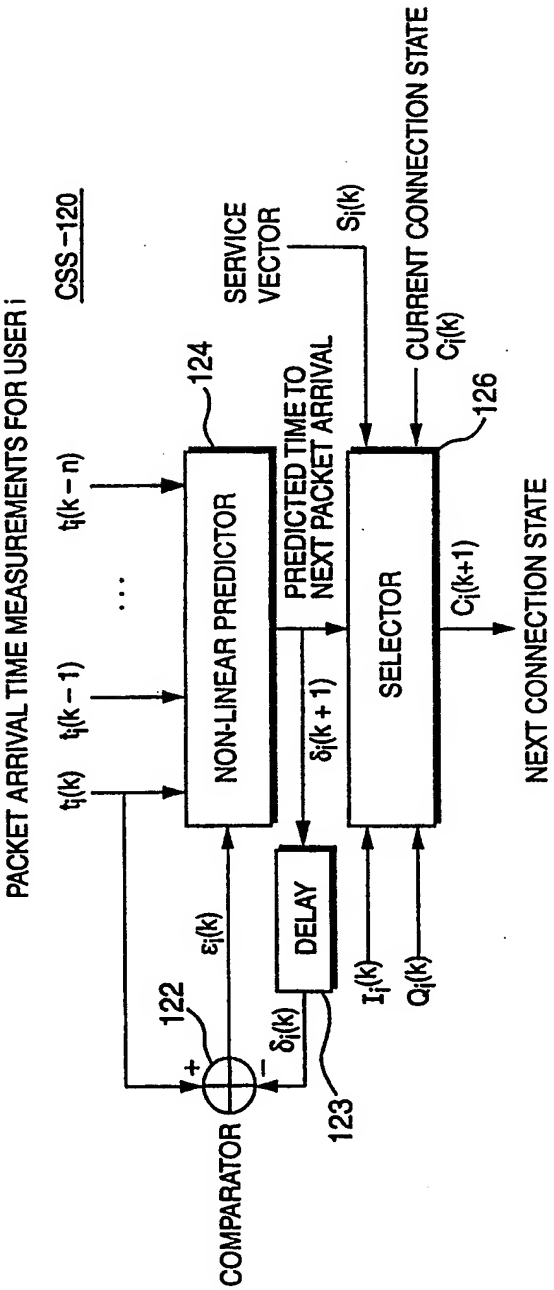

PACKET ARRIVAL TIME MEASUREMENTS FOR USER i
CSS –120
$t_i(k)$
$t_i(k-1)$
$t_i(k-n)$
NON-LINEAR PREDICTOR
124
SERVICE VECTOR
$S_i(k)$
PREDICTED TIME TO NEXT PACKET ARRIVAL
$\delta_i(k+1)$
CURRENT CONNECTION STATE
$C_i(k)$
126
SELECTOR
$C_i(k+1)$
NEXT CONNECTION STATE
DELAY
$I_i(k)$
$Q_i(k)$
122
$\varepsilon_i(k)$
$\delta_i(k)$
123
COMPARATOR

Fig. 13

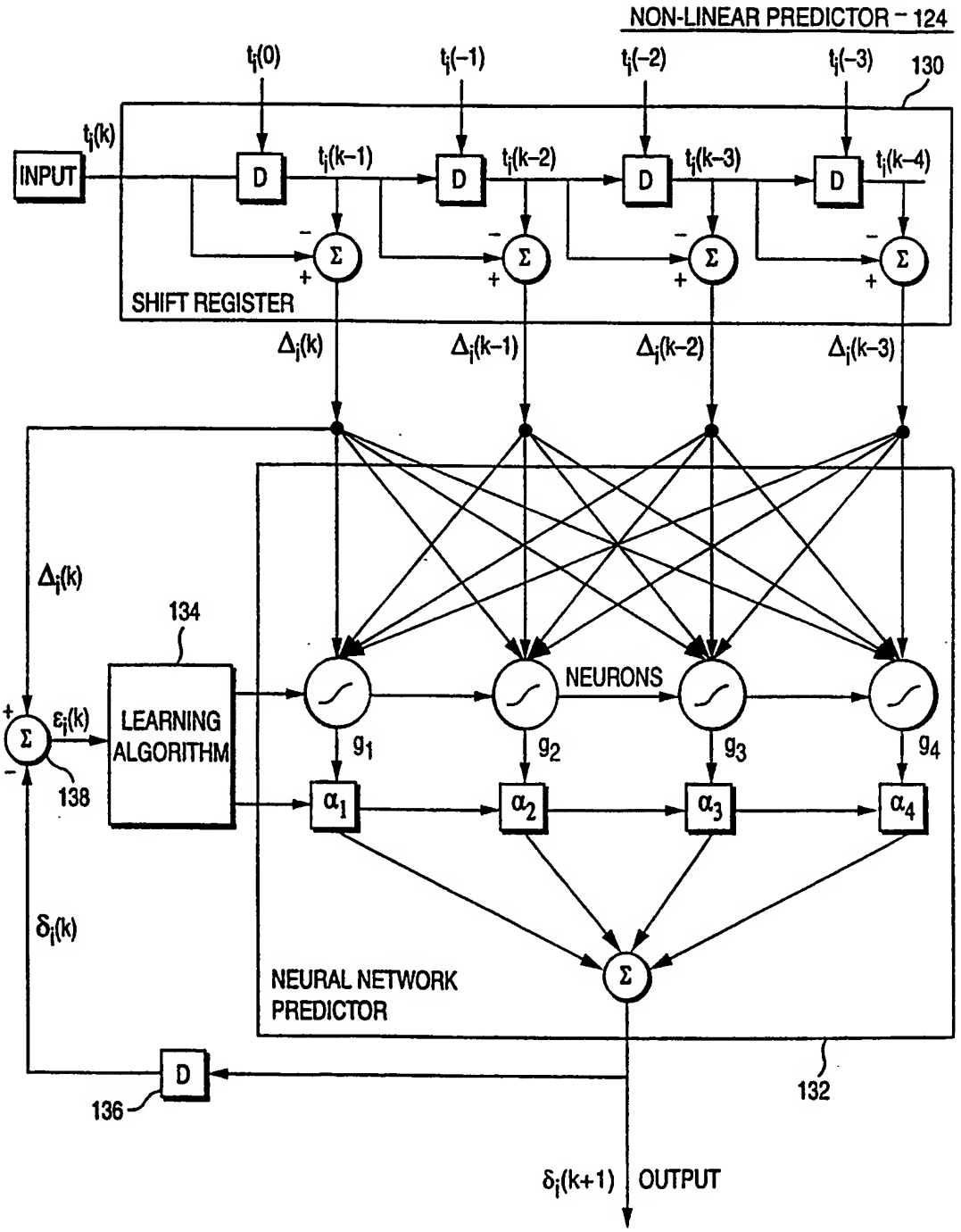

NON-LINEAR PREDICTOR – 124
$t_i(0)$
$t_i(-1)$
$t_i(-2)$
$t_i(-3)$
130
$t_i(k)$
INPUT
D
$t_i(k-1)$
$t_i(k-2)$
$t_i(k-3)$
$t_i(k-4)$
Σ
SHIFT REGISTER
$\Delta_i(k)$
$\Delta_i(k-1)$
$\Delta_i(k-2)$
$\Delta_i(k-3)$
134
LEARNING ALGORITHM
$\varepsilon_i(k)$
138
NEURONS
g_1
g_2
g_3
g_4
α_1
α_2
α_3
α_4
$\delta_i(k)$
NEURAL NETWORK PREDICTOR
132
136
$\delta_i(k+1)$
OUTPUT

Fig. 14

INTERNATIONAL SEARCH REPORT

Ir ational Application No
PCT/SE 98/02058

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04Q7/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04Q H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 673 259 A (QUICK JR ROY F) 30 September 1997 see column 3, line 65 - column 4, line 1 see column 4, line 27 - line 38 see column 7, line 22 - line 32 see column 10, line 5 - line 17 see column 10, line 54 - column 11, line 58 see column 15, line 27 - line 44 see column 17, line 57 - line 64 see column 23, line 37 - column 27, line 13 --- -/--	1-8, 10-30, 40-65,70

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 March 1999	17/03/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Gerling, J.C.J.

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INTERNATIONAL SEARCH REPORT

Int tional Application No
PCT/SE 98/02058

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category '	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98 24250 A (ERICSSON TELEFON AB L M) 4 June 1998 see page 5, line 12 - page 6, line 10 see page 7, line 12 - line 24 see page 9, line 11 - page 10, line 18 see page 11, line 5 - page 12, line 24	1-6,10, 12,13, 15-18, 21,22, 24,25, 27,28, 45-48,50
X	US 5 666 348 A (THORNBERG CARL MAGNUS ET AL) 9 September 1997 see column 2, line 28 - line 55 see column 4, line 7 - line 59 see column 5, line 37 - line 38 see column 6, line 10 - line 19 see column 6, line 46 - column 7, line 31 see column 8, line 39 - line 52 see column 9, line 55 - column 10, line 3 see column 12, line 13 - column 14, line 53	1-4,7,9, 10, 12-18, 20,24, 25, 27-30,44
X	WO 96 37081 A (ROKE MANOR RESEARCH ;DAVIS SIMON PAUL (GB)) 21 November 1996 see page 4, line 9 - page 5, line 18 see page 6, line 9 - page 7, line 12 see page 10, line 6 - line 15 see page 13, line 12 - page 14, line 12 see page 15, line 17 - line 20 see page 16, line 15 - page 17, line 24	1-4, 9-13, 15-18, 20, 24-30, 40-42, 44,55, 78-85
A	SCHIEDER A ET AL: "GRAN - A NEW CONCEPT FOR WIRELESS ACCESS IN UMTS" ISS '97. WORLD TELECOMMUNICATIONS CONGRESS. (INTERNATIONAL SWITCHIN SYMPOSIUM), GLOBAL NETWORK EVOLUTION: CONVERGENCE OR COLLISION? TORONTO, SEPT. 21 - 26, 1997, vol. 2, 21 September 1997, pages 339-345, XP000704485 ABDALLAH ABI-AAD ET AL -/--	

1

INTERNATIONAL SEARCH REPORT

Int tional Application No
PCT/SE 98/02058

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	Z. FAN ET AL: "ATM Prediction Using FIR Neural Networks" IFIP WORKSHOP TC6,2 July 1995, pages 34/1-34/10, XP002085769 Bradford (GB) ---	
A	YANG C -Q ET AL: "A TAXONOMY FOR CONGESTION CONTROL ALGORITHMS IN PACKET SWITCHING NETWORKS" IEEE NETWORK: THE MAGAZINE OF COMPUTER COMMUNICATIONS, vol. 9, no. 4, 1 July 1995, pages 34-45, XP000526590 -----	

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int tional Application No
PCT/SE 98/02058

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 5666348 A	09-09-1997	AU 7005196 A	09-04-1997
		CN 1201583 A	09-12-1998
		EP 0852102 A	08-07-1998
		WO 9711570 A	27-03-1997
WO 9637081 A	21-11-1996	CN 1157083 A	13-08-1997
		EP 0771510 A	07-05-1997
		JP 10503357 T	24-03-1998